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GEOLOGY OF THE NORTHERN CONTACT AREA OF ARRIGETCH PEAKS PLUTON, BROOKS RANGE, ALASKA

A

THESIS

Presented to the Faculty of the University of Alaska

in Partial Fulfillment of the Requirements

for the Degree of

MASTER OF SCIENCE

By

David D. Adams, B.S.

Fairbanks, Alaska

May 1983

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GEOLOGY OF THE NORTHERN CONTACT AREA OF

ARRIGETCH PEAKS PLUTON, BROOKS RANGE, ALASKA

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ABSTRACT

The Arrigetch Peaks pluton consists of granite orthogneiss and is thought to have an anatectic origin.

The pluton and country rocks have been regionally metamorphosed in the greenschist facies. Country rocks include the Skajit Formation, a thick unit of impure marble containing possible Silurian to Upper Devonian fossils and interlayers of greenschist, calc-schist and quartz schist. Other metasedimentary rock units of Proterozoic (?) to Devonian (?) age are calcareous, quartzose or pelitic and occur above and below the Skajit Formation.

The contact-metamorphic zone adjacent to the intrusion is well preserved and contains hornfels, calc-silicate marble, skarns and veins. Mineral zones in one area consist of garnet-pyroxene-bearing marble, plagioclase-bearing marble and tremolite-bearing marble. Crosscutting relations and replacement textures indicate that development of hornfels preceeded most skarn and vein formation. Skarns are subordinate to hornfels and contain calc-silicate minerals or magnetite and local sulfides.

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PREVIOUS WORK

The first geologic work in the central Brooks Range was done by Schrader (1904), who first defined the Skajit Limestone at a location on the John River. Smith (1913) and Smith and Mertie (1930) noted the presence of gneissic granitic rocks near the Alatna River. Fritts and others (1971) described the geology and geochemistry near Walker Lake. Brosge and Reiser (1971) and Brosge and Pessel (1977) provided preliminary reconnaissance geologic maps at a scale of 1:250,000. Grybeck and others (1977) provided the first regional geologic map of the Brooks Range at a scale of 1:1,000,000. Some of the structure and stratigraphy of the Schwatka Mountains are discussed in Mull, 1977 and in Mull and Tailleur, 1977. The most recent maps, investigations and reports concerning the Survey Pass quadrangle are found in Nelson and others, 1978, Nelson and Grybeck, 1978, 1979 and 1980 and in Dillon and others, 1980a and 1980b.

Many radiometric age-dates have been determined for the Arrigetch Peaks pluton. The results of K-Ar determinations are described in Turner, 1973 and Turner and others, 1978 and 1979. U-Pb ages of zircons are presented in Dillon, 1979. The results and discussion of Rb-Sr age-dating are given in Silberman and others, 1979.

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INTRODUCTION

The Arrigetch Peaks pluton is located in the central Survey Pass quadrangle in the heart of the Brooks Range, northern Alaska. This study focuses on the northern contact of the pluton, an area which lies just north of 67°24' north latitude (Figure 1). The geographical reference points in Figure 2 and Plate 1 will be used throughout this text. Access to the field area was gained mostly by floatplane and rigorous backpacking; no roads exist in the area. Techniques used for this study were geologic mapping and petrography supported by powder camera X-ray diffraction.

Natives and trappers were probably the first to visit the Arrigetch Peaks area but written accounts of early visits are unknown. The name "Arrigetch" means "fingers of the hand extended" and comes from an Eskimo legend concerning a giant. Phillip Smith made a few notes about the "needle-like peaks" in his early accounts (Smith, 1913). Other early explorers include Earnie Johnson and Robert Marshall who traveled around the central Brooks Range in the 1930's.

The Arrigetch Peaks area abounds with high, rugged relief and alpine environments. Several glaciers occur in the interior pluton area. Glacial landforms are abundant and include aretes, horns, cirques and U-shaped valleys. Moraines are common in the valley floor areas and talus deposits are very common in the higher slopes where steep outcrops of bedrock occur. Much of the orthogneiss

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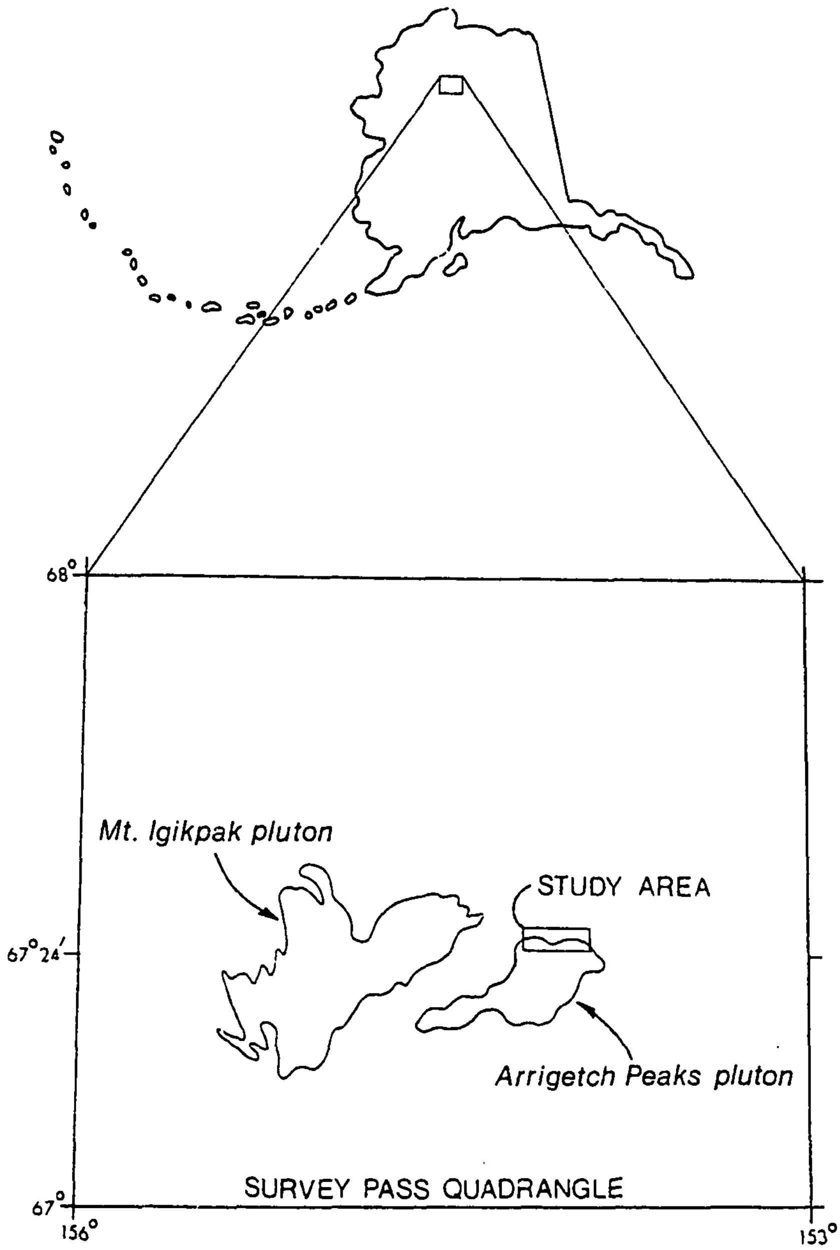

Figure 1. Map showing location of study area.

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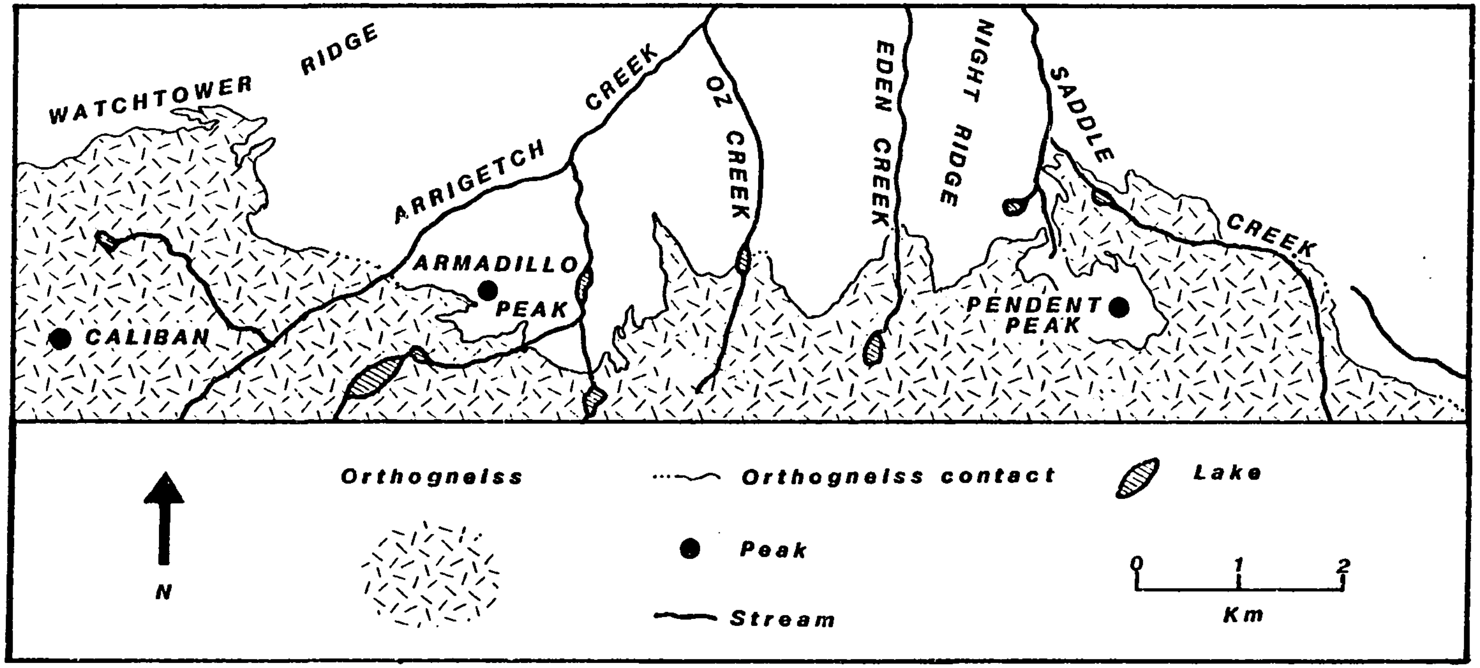

Figure 2. Map showing geography and place names referred to in text.

which crops out in the study area is inaccessible except by helicopter or technical rock climbing and hence most of the traversing, mapping and sampling was confined to the ridges north of the orthogneiss massif.

The Arrigetch Peaks pluton is largely granite in composition (Nelson and Grybeck, 1980 and Streckheisen, 1967). The pluton consists of "orthogneiss" which designates gneiss formed by metamorphism of crystalline igneous rocks (Spry, 1969). Regionally metamorphosed country rocks include marble, calc-schist, quartz schist, mica schist and greenschist and have foliations typically formed by mica or amphibole. The contact zone is well preserved, typically ranges up to several tens of meters in thickness and contains hornfels, calc-silicate marble and locally developed skarns. Mineral abbreviations which are used in figures are listed in Table 1.

The purpose of this study is to examine and describe the contact-metamorphic and adjacent rocks in the study area. These rocks have not been studied in detail. Little is known about the contact aureoles of plutons in this region. Emphasis is given to mineral assemblages and textures of the metamorphosed carbonate rocks to interpret the conditions and history of contact-metamorphism. Examples of skarn and other mineralization of economic interest are cited.

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Table 1

Mineral Abbreviations Used in Figures

ac	actinolite	id	idocrase
af	alkali-feldspar	il	ilmenite
an	anorthite	mt	magnetite
bi	biotite	ph	phlogopite
bs	bismuthite	pl	plagioclase
ca	calcite	pr	prehnite
ch	chlorite	px	pyroxene
cp	chalcopyrite	py	pyrite
cz	clinozoisite	qu	quartz
di	diopside	se	sphene
do	dolomite	si	siderite
ep	epidote	sp	sphalerite
ga	garnet	ta	talc
gl	galena	tr	tremolite
gr	grossular	wm	white mica
gu	grunerite	wo	wollastonite
		zo	zoisite

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REGIONAL GEOLOGY

The central Brooks Range contains abundant mid-Paleozoic metamorphic rocks (Grybeck and others, 1977). A central belt of higher metamorphic grade contains granite orthogneiss plutons, Silurian-Devonian marble and Proterozoic(?)-Lower Paleozoic schist (Figure 3). Northward and southward the metamorphic grade decreases finally into areas that are unmetamorphosed (Grybeck and others, 1977). A wide variety of rock types occur in the central Brooks Range and many formal rock units are recognized. Despite considerable geologic work disagreement concerning the structural evolution of the Brooks Range still exists (Tailleur, 1973 and Yorath and Norris, 1975).

The Arrigetch Peaks and Mt. Igikpak plutons form large granitic massifs which are flanked by low- to medium-grade schist and marble (Figure 3). Nelson and Grybeck (1980) show that compositions of these plutons are primarily granite and range from alkali-feldspar granite to tonalite of the classification of Streckheisen (1967). Regionally the orthogneisses have well developed foliations, but locally only a weak foliation is found.

Intrusive contacts between the plutons and country rocks are evidenced by the occurrence of aplitic and pegmatitic dikes and sills and by hornfels and skarn (Dillon and others, 1980a). The youngest rocks clearly intruded by the plutons are thick marbles of the Skajit Formation and mid- to Upper Devonian metasediments.

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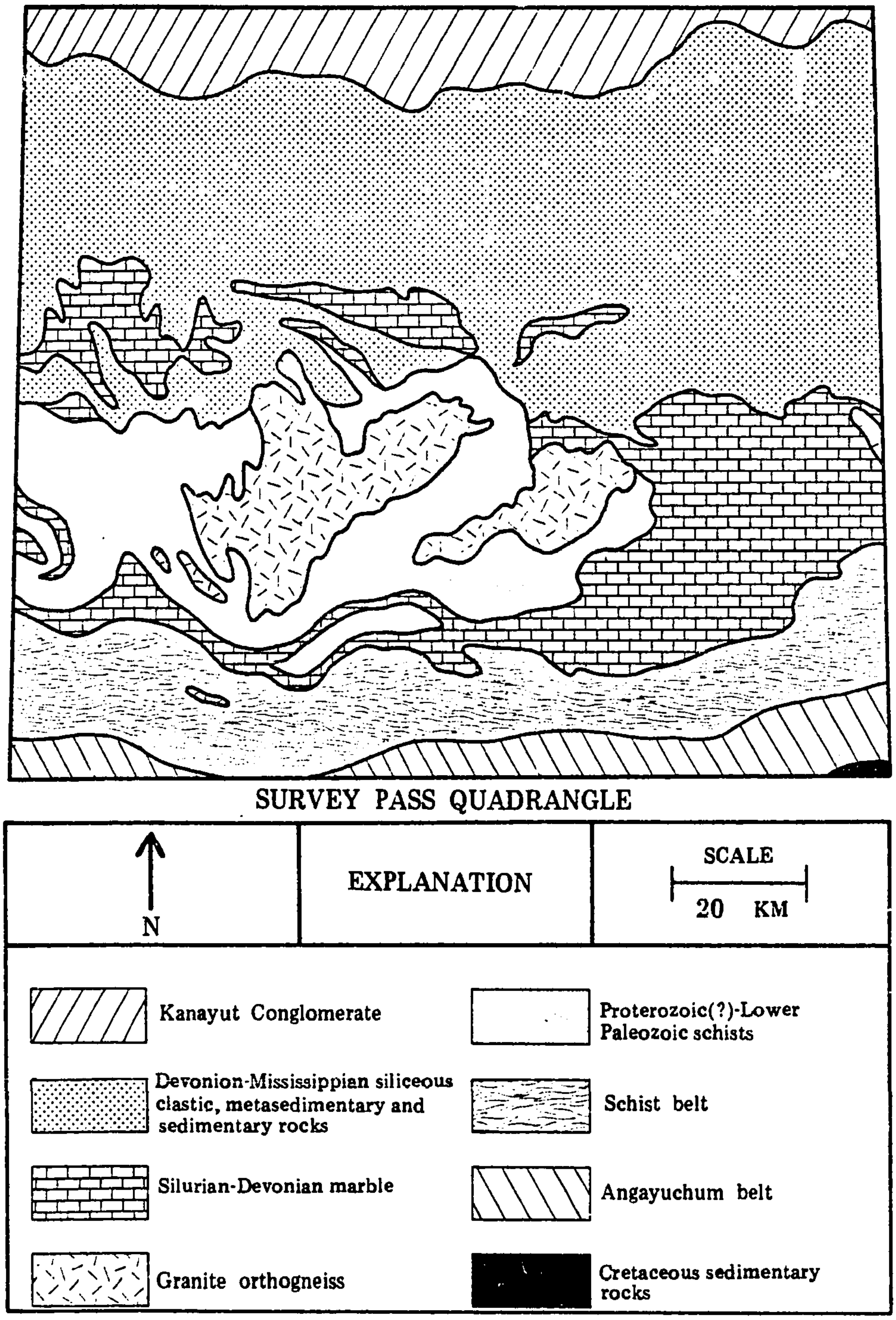

Figure 3. Regional geology of the Survey Pass quadrangle generalized from Grybeck and others (1977) and Nelson and Grybeck (1980).

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One fault contact has been observed along the south margin of the Arrigetch Peaks pluton (Nelson and Grybeck, 1980).

Radiometric age data of the plutons indicates a mid-Devonian age of magmatic crystallization followed by a Cretaceous metamorphic overprint (Dillon and others, 1980a and Turner and others, 1979). On trend to the east and west of these plutons are other plutons having Devonian or Precambrian radiometric ages (Dillon and others, 1980a).

Thick, Silurian to Devonian carbonate rocks which correlate with the Skajit Formation crop out extensively across the central Brooks Range (Figure 3). The Skajit Formation is intruded by the mid-Devonian granite plutons and is highly deformed in most areas. It consists of massive or layered calcite and dolomitic marble with local interlayers of greenschist, calc-schist and quartz schist. Fossils are rarely found in the Skajit Formation. Silurian- to Devonian-aged corals and one Ordovician- to Devonian-aged conodont genus have been found in the Survey Pass quadrangle (Nelson and Grybeck, 1980).

The Skajit Limestone was first described by Schrader (1904) at a location on the John River between Crevice Creek and Wolverine Creek. Henning (1982) made a composite section of the Skajit Formation near Rock Creek in the central Brooks Range. There, the Beaucoup Formation (which is not found in the Arrigetch Peaks area) conformably overlies the Skajit. The lower limit of the Skajit Formation in the Rock Creek area is an unconformity which separates

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it from Precambrian orthogneiss or Lower Paleozoic (?) calc-schist and quartz schist.

North of the central orthogneiss-marble-schist belt occur successive, east- west-trending belts of Devonian-aged siliceous clastic rocks overlain locally by Mississippian(?)-aged rocks (Figure 3). The Upper Devonian Hunt Fork Shale Formation which comprises much of these belts overlies the Skajit Formation and also in part forms its lateral stratigraphic facies equivalent (Dillon, pers. comm., 1981). The Hunt Fork Shale Formation includes a lower shale member (metamorphosed to slate, phyllite and schist) and an upper wacke sandstone and metasandstone member. Further northward, the Upper Devonian Kanayut Conglomerate (non-marine sandstone, shale and conglomerate) succeeds and overlies the Hunt Fork Shale (Nilsen and Moore, 1982). The Mississippian rocks include the Kekiktuk Conglomerate (interbedded metasandstones and metaconglomerates), and Kayak Shale (phyllite or slate with interbedded metasiltstone and metasandstone) and the Lisburne Group (limestone or marble and bedded novaculite) (Nelson and Grybeck, 1980 and Nilsen and Moore, 1982).

South of the central orthogneiss-marble-schist belt lie three major east-west-trending belts of rock (Figure 3). The first is the "schist belt" of the Brooks Range (Nelson and Grybeck, 1979). Rocks within this belt have a wide range of compositions (mostly quartz-, mica- and feldspar-schists, greenschists and lesser metacarbonates) and possible ages (Precambrian (?) to Lower

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Mississippian (?)). The boundary between the schist belt and the central belt is a poorly understood structural and metamorphic break known as the "Walker Lake lineament," which at present, is thought to be a folded unconformity or thrust fault (Nelson and Grybeck, 1980). Southward the schist belt is separated from the Angayucham terrane (a belt of greenstone and some phyllite, limestone and chert) by another major boundary which is probably a south-dipping thrust fault (Dillon and others, 1981). Fossils (radiolaria) from interlayered (?) cherts within this belt range from Mississippian to Triassic in age (Nelson and Grybeck, 1980). The southernmost rocks of the range are unmetamorphosed pebble conglomerates, sandstones and siltstones which contain Early Cretaceous plant fossils (Nelson and Grybeck, 1980).

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STRUCTURES

Many types of small- to large-scale structures can be found in the northern contact area of the Arrigetch Peaks pluton. Structural features within the pluton were not studied in detail due to their inaccessibility. Grybeck and Nelson (1981) give a complete review of the structure of the Survey Pass quadrangle.

Structures of the Arrigetch Peaks pluton are largely formed by deformed compositional layers but folded joints can be seen locally. Compositional layering occurs as alternating felsic and mafic bands which are delicately folded. Contacts of the pluton with adjacent rocks range from concordant to discordant. In the central portions of the study area the pluton contact dips steeply northward or vertical. Just north of the orthogneiss massif the contact apparently flattens (Plate 1, cross section D-D'). In the eastern portion of the study area the intrusive contact has a shallow, northerly dip (Plate 1, cross section E-E').

The most common structures of the country rocks consist of large-scale compositional layering and are typically gently-dipping to the north. This layering is probably transposed, sedimentary bedding and is parallel to foliations defined by mica.

Near the intrusion structures in banded hornfels are formed by contorted layers consisting of calc-silicate minerals and/or calcite which are thought to have originated from lithologic interbedding of the parent rock. However, these types of structures

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are absent in skarns. Semipenetrative fabrics or slip cleavages can be seen locally in hornfels.

The most common types of folds in the country rocks are isoclinal folds (Figure 4) but large, open, gentle folds also occur. Most of the gentle folds have west- to northwest-trending fold axes which plunge gently to the northwest (Plate 1). Isoclinal fold axes have highly variable trends and plunges. Amplitudes of isoclinal folds range in scale from microscopic to at least tens of meters. Since some folds deform the intrusive contact and post-intrusion metamorphic structures, some intense deformation must have occurred after intrusion and after regional metamorphism.

Exposures of faults are rare but slickensided surfaces and breccia zones are found locally near Saddle Creek and Pendent Peak (Plate 1). One slickensided surface near Saddle Creek dips 80° to the northeast. Since scattered outcrops of orthogneiss and contact-metamorphic rocks occur near the base of the thick marble unit northeast of Saddle Creek and since the one observed fault near Saddle Creek does not juxtapose different lithologies, displacement along a possible fault zone near Saddle Creek is thought to be small.

Joints in orthogneiss are very common but lack consistent strikes. The joints dip steeply in most places.

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Figure 4. Photograph of isoclinal fold in marble on Night Ridge. Trend and plunge of fold is northwest and amplitude is approximately .4 km.

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ORTHOGNEISS

Introduction

Orthogneiss of the northernmost portions of the Arrigetch Peaks pluton is well exposed in the study area. The best exposures are on steep walls which rise to over 1,000 meters above valley floors and are sheer and inaccessible in many places. The pluton crops out for approximately 200 square kilometers to the south and southwest of the study area and may be connected at depth with the larger Mt. Igikpak pluton (Figure 3) to the west (Grybeck and Nelson, 1981). The northern contact of the Arrigetch Peaks pluton is an east-west-trending intrusive contact associated with a complex zone of contact-metamorphic and metasomatic rocks (Plate 1).

Mineralogy and Chemistry

Modal and chemical data provides evidence that the Arrigetch Peaks pluton consists largely of granite by the classification of Streckheisen (1967). Modal quartz-feldspar ratios of 24 out of 28 samples plot in the granite field (Nelson and Grybeck, 1980 and Streckheisen, 1967). Petrographic estimations of compositions of many orthogneiss samples from the study area typically range from granite to quartz monzonite. CIPW norm calculations average 30%-40% quartz, 25%-30% orthoclase and 20%-30% albite. Normative corundum ranges from .5% to 3.5%.

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Table 2

Whole Rock Major Oxide Data in Weight Percent for Arrigetch Peaks Orthogneiss

Values determined by X-ray fluorescence spectrometry except for FeO (determined by volumetric chemical analysis).

Sample	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	LOI	H_2O-	Total
1	75.24	10.40	3.34	4.45	0.82	0.46	2.51	2.35	0.29	0.07	0.09	0.58	0.60	101.20
2	77.61	11.25	0.55	2.16	0.00	0.63	3.08	4.20	0.18	0.07	0.04	0.71	0.13	100.61
3	77.12	11.33	0.28	1.19	0.00	1.33	2.96	5.09	0.12	0.04	0.02	0.36	0.50	100.34
4	76.38	12.27	0.40	1.16	0.05	1.63	4.56	1.09	0.16	0.05	0.07	0.34	0.36	98.52
5	74.43	12.85	0.24	1.44	0.01	0.37	3.60	5.47	0.16	0.05	0.02	0.32	0.35	99.31
6	69.31	14.42	1.77	3.46	1.45	1.09	2.46	3.63	0.77	0.12	0.03	1.30	0.32	100.13
7	82.74	8.67	0.86	1.58	1.14	1.01	2.90	0.93	0.15	0.09	0.05	0.93	0.20	101.25

Samples 1-5: coarse facies orthogneiss
Sample 6: schistose orthogneiss
Sample 7: aplitic orthogneiss

Major oxide analyses of samples of fresh orthogneiss from the study area are listed in Table 2. The major oxide values indicate that these rocks are silica oversaturated and peraluminous by the classification of Shand (1927) ($Al_2O_3/(Na_2O + K_2O + (CaO/2)) > 1.1$). An initial $^{87}Sr/^{86}Sr$ ratio for orthogneiss of the Arrigetch Peaks and Mt. Igikpak plutons has a value of about .714 ± 0.003 (Silberman and others, 1979).

Textures and Structures

Secondary textures and structures predominate in the Arrigetch Peaks pluton and are due to regional metamorphic overprinting. A prominent foliation is defined by recrystallized biotite and white mica. Perthite augen are surrounded by this foliation. In thin section perthite and quartz commonly have granulated textures and some of the quartz has been recrystallized. Folds in the granite orthogneiss range from large domal structures to small-scale isoclinal folds.

Relict igneous textures and structures are found in the Arrigetch Peaks pluton. Relict porphyritic textures are common; relict granitic textures and orbicular structures are rare. In some areas the orthogneiss contains abundant injection dikes of aplitic material. Relict schleiren are seen in marginal areas and large- or small-scale banding is common (Figure 5). White or smokey quartz veins are abundant. Myrmekitic textures in perthite are seen in thin section, but some of these textures could be

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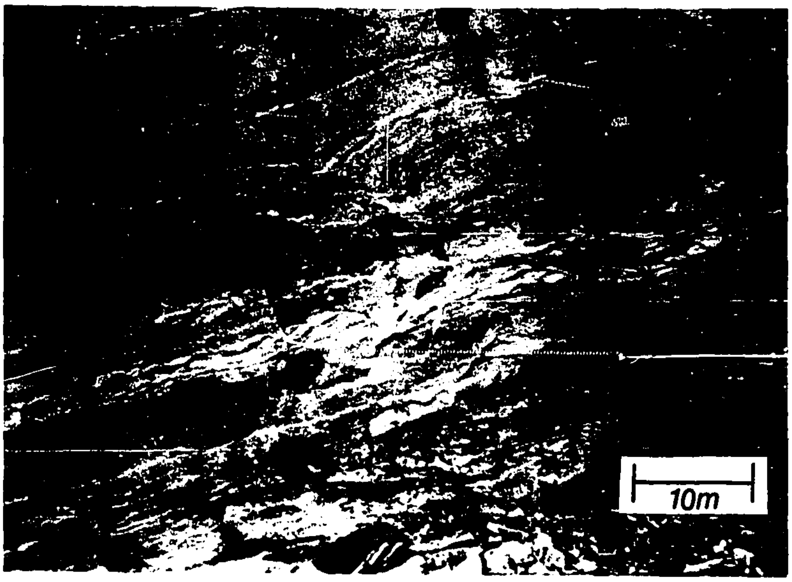

Figure 5. Photograph of banding and relict schleiren in exposed wall of orthogneiss.

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metamorphic in origin. Plagioclase locally appears to mantle perthite and could represent relict rapakivi texture.

Age

Radiometric ages have been determined for the Arrigetch Peaks pluton; all of these data are from portions of the pluton south of the study area. The majority of the ages cluster in the Devonian and Cretaceous periods (Dillon and others, 1980a and Turner and others, 1979).

Dillon and others (1980a) present zircon U-Pb data for samples of quartz monzonite orthogneiss of the Arrigetch Peaks pluton. Concordant U-Pb and Pb-Pb ages for one sample are 357 m.y. and a discordant Pb-Pb age for another sample is 375 m.y. The concordant 357 m.y. age is interpreted to represent the age of magmatic crystallization (Dillon and others, 1980a).

A Rb-Sr isochron age of 373 ± 25 m.y. for the Arrigetch Peaks and Mt. Igikpak plutons further supports a Devonian age for magmatic crystallization of the pluton (Silberman and others, 1979).

K-Ar ages have been determined using minerals from the pluton and from the contact zone of the pluton. Ages obtained from biotite and muscovite from the pluton range from 86 m.y. to 92 m.y. (respectively) (Brosge and Reiser, 1971 and Turner and others, 1978). Ages obtained from biotite and hornblende are 95 ± 3 m.y. (respectively) (Silberman and others, 1979). Since hornblende has a higher argon blocking temperature than biotite and muscovite (Hanson and Gast,

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1967), Silberman and others (1979) interpret these K-Ar ages to indicate that the argon retention temperature for hornblende was attained prior to the time the argon retention temperatures for biotite and muscovite were attained. This is suggestive of final cooling of these minerals in the Late Cretaceous following metamorphism sometime between the Middle Devonian and mid-Cretaceous (Silberman and others, 1979). The K-Ar ages obtained from micas from the pluton are interpreted by Turner and others (1978) to indicate regional metamosphism in the Mesozoic.

Coarse-grained Orthogneiss

Coarse-grained orthogneiss predominates in the southern portion of the study area (Plate 1, unit Dgr) and the interior area of the Arrigetch Peaks pluton. Coarse-grained orthogneiss typically has a granite composition and coarse-to very coarse-grain size and commonly consists of augen gneiss (Figure 6). Contacts of coarse-grained orthogneiss with schistose facies orthogneiss are mostly gradational whereas contacts with hornfels are sharp.

Coarse-grained orthogneiss consists of the dominant minerals quartz, alkali-feldspar, plagioclase, biotite and white mica along with minor amounts of accessory minerals. Quartz averages 15% to 30% of the rock but ranges up to approximately 45%. Feldspars make up as much as 40% of coarse-grained orthogneiss. Alkali-feldspar occurs mostly as perthite and ranges from 15% to 40% in granite types and 15% to 30% in quartz monzonite types. Biotite and white

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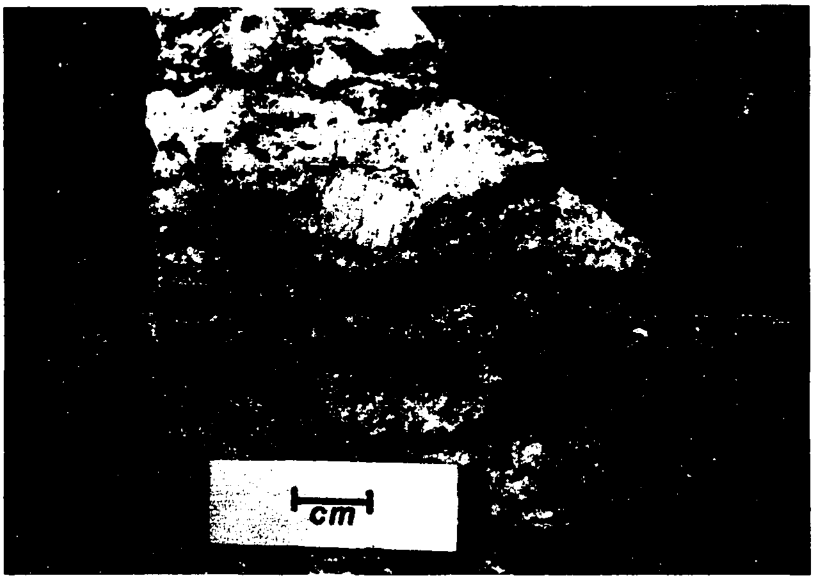

Figure 6. Photograph of hand specimen of coarse-grained augen gneiss. Augen consist of alkali-feldspar. Foliation is defined by biotite and white mica.

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mica are present in approximately equal proportions (5% to 10%) in many samples; white mica is commonly subordinate in granite types. Biotite is altered to chlorite, sphene or rutile and locally replaces alkali-feldspar. Accessory minerals which occur in coarse facies orthogneiss include zircon, apatite, ilmenite, allanite, fluorite, cassiterite, and garnet. Secondary minerals include biotite, white mica, chlorite, garnet, sphene, epidote, clinozoisite, calcite, hematite and kaolinite.

Fine-grained granulated quartz and coarse-grained, recrystallized quartz forms lenses and layers. Quartz grains are commonly strained and have some sutured boundaries. Some quartz forms idioblastic overgrowths.

Exsolution has formed vein or patch perthite textures in perthite augen (Figure 7). Chessboard albite texture is common in exsolved plagioclase in perthite and in larger, plagioclase crystals. Porphyroclasts of perthitic alkali-feldspar commonly have granulated edges and locally contain inclusions of quartz or mica.

Plagioclase occurs in a fine-grained groundmass or as large, subidioblastic grains with granulated boundaries. Alteration of plagioclase to fine-grained white mica or epidote is common and locally gives rise to mortar texture.

Biotite and white mica are recrystallized and define the foliation of the pluton. Biotite locally contains inclusions of zircon and pleochroic halos. White mica occurs as subidioblastic grains or as a fine-grained alteration mineral.

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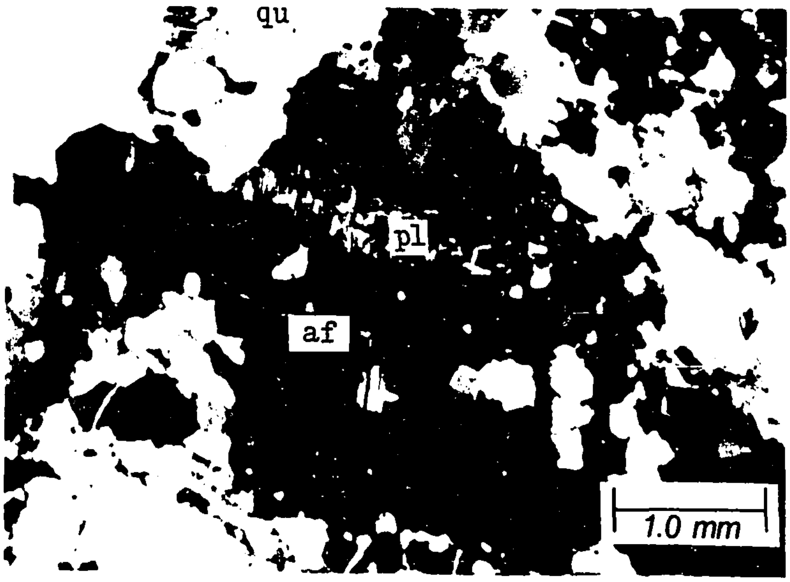

Figure 7. Photomicrograph of thin section of coarse-grained orthogneiss showing vein and patch texture in perthite porphyroclast. Chessboard albite texture is seen in vein of plagioclase.

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Schistose Orthogneiss

Schistose orthogneiss is a medium- to coarse-grained, strongly foliated, micaceous variety of orthogneiss which is not abundant in the study area. It crops out in irregular zones or relict schlieren near the northern margin of the Arrigetch Peaks pluton (Plate 1, unit Dso) and probably in other areas of the pluton to the south as well. Schistose orthogneiss is transitional with coarse-grained orthogneiss and locally resembles mica-quartz schist and paragneiss in outcrop.[1] Foliations of schistose orthogneiss and of country rocks are commonly concordant.

Schistose orthogneiss contains a high proportion of mica compared with coarse-grained orthogneiss. Mineralogy commonly consists of quartz+plagioclase+alkali-feldspar+biotite+white mica+chlorite with accessory zircon and secondary calcite+sphene+epidote.[2] In some samples of schistose orthogneiss biotite or biotite+white mica form the most abundant minerals. Perthitic alkali-felspar is typically altered to fine-grained white mica, chlorite or kaolinite; plagioclase is altered to fine-grained white mica, epidote, clinozoisite or calcite. Biotite is locally altered to chlorite or sphene. Schistose orthogneiss has a well-developed metamorphic fabric defined by oriented biotite and/or white mica and secondary chlorite.

[1]Hyphenated mineral sequences indicate increasing abundance order.
[2]Mineral sequences adjoined by "+" signs indicate decreasing abundance order; "±" indicates that mineral occurs locally.

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Figure 8. Photograph of outcrop of hornfels with crosscutting dikes of aplitic rock. Attitude of semipenetrative cleavage in hornfels, shown by attitude of rock hammer, dips north. Dikes are slightly offset by faulting.

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Aplitic Rocks

Aplitic rocks occur in dikes and sills in the Arrigetch Peaks pluton and in hornfels or schistose rocks in the northern contact zone of the pluton (Figure 8 and Plate 1). The dikes range up to .5 m in width and some of the aplitic rock occurs in veinlets on the scale of millimeters.

Mineralogy of aplitic rock is similar to that of coarse facies but contains less mica. Mineralogy of aplitic rocks typically consists of quartz (50% to 75%), feldspar (20% to 40%), mica (less than 5%) and accessory minerals. Alkali-feldspar is commonly perthitic and plagioclase is albite-oligoclase (An_5 to An_{10}). White mica and biotite are rare. Minor amounts of kaolinite and fine-grained white mica occur as alteration products of feldspar. Accessory minerals include zircon, garnet and tourmaline. Aplitic rocks typically have fine- to medium-grained, relict allotriomorphic, granular textures. Feldspars are most commonly subidioblastic. Garnet and tourmaline occur as aggregates of idioblastic crystals.

Plutonism

The history of intrusion of the Arrigetch Peaks pluton is not firmly established. U-Pb and Rb-Sr age data and the composition of the pluton support a model of mobilization of crustal material followed by magmatic crystallization which ended in the mid-Devonian (Silberman and others, 1979 and Dillon and others, 1980a).

Early crystallizing phases included accessory minerals such as zircon or apatite. Feldspars, quartz, biotite, white mica

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and other minerals then crystallized. Cassiterite, fluorite, allanite and other minerals formed during late stage crystallization. Clinozoisite, epidote, garnet and chlorite could have formed during late stage alteration or during postemplacement metamorphism. The high initial $^{87}Sr/^{86}Sr$ ratio of the Arrigetch Peaks and Mt. Igikpak plutons in addition to the peraluminous composition and presence of ilmenite, fluorite and cassiterite suggest affinities with S-type and ilmenite series granitoids of the classifications of Chappell and White (1977) and Ishihara (1981) (respectively).

The emplacement depth of the Arrigetch Peaks pluton can be estimated from the stratigraphic thickness of Silurian to Devonian rocks in the region, which is approximately 4500 meters. This estimate does not represent the true thickness of these rocks at the time of intrusion because these rocks are intensely deformed. Also, since these rocks contain widespread unconformities and are partly overlain by unconformities, this estimate may represent a minimum thickness at the time of intrusion. The largely discordant contact of the Arrigetch Peaks pluton is a characteristic of epizonal plutons (0 to 8 kilometer depths of emplacement) of the classification of Buddington (1959). Other features of the pluton, such as concordant contacts and large domal structures, are suggestive of deeper emplacement following this classification. Additional evidence against shallow level intrusion is the lack of much fracturing and brecciation in the adjacent hornfels and the lack of extensive skarn development.

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Evidence which supports a major orogeny approximately during the Devonian involving magmatism, tectonism and metamorphism includes: 1) Devonian U-Pb zircon ages from the Arrigetch Peaks and other plutons and 2) widespread unconformities in Upper Devonian metasediments as well as nonconformable contacts between Mississippian rocks and the Devonian plutons or pre-Devonian basement rocks (Dillon and others, 1980a).

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METASEDIMENTARY AND METAVOLCANIC ROCKS

Introduction

A thick section of metasedimentary rocks with minor interlayered metavolcanic rocks is exposed north of the pluton in the study area (Plate 1). 500 to 800 meters of marble and schist are exposed in the west wall of Arrigetch Creek valley. Exposures of these rocks are 300 meters or less in thickness in the central and eastern portions of the study area. Isoclinal folding is common and has caused structural thickening and thinning of these units.

The composite stratigraphy of these rocks consists of a thick unit of marble underlain and overlain by calcareous, quartzose or pelitic rocks (Plate 1). Beneath the thick marble unit is a schist unit which is commonly garnet-, biotite- and quartz-bearing and includes local marble interlayers. The thick marble unit contains local, interlayered greenschists and a lower unit of white marble. Chlorite, white mica, biotite and garnet are the most common minor minerals found in quartz, mica or calc-schist. The thick marble unit is correlated with the Skajit Formation because of lithologic similarity and because of a possible Silurian to Devonian fossil coral which was found. Units overlying the thick marble unit are thought to correlate with mid- to upper Devonian metasediments which overlie the Skajit Formation elsewhere in the Survey Pass quadrangle, and could also correlate in part with the Hunt Fork Shale Formation. Units underlying the

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thick marble unit may correlate with the lower part of the Skajit Formation or with sub-Skajit rocks.

Marble

Marble of the Skajit Formation is the most abundant metasediment in the study area and typically forms steep cliffs on the ridges north of the pluton. Gray and white marble were distinguished; gray marble includes laminated gray and white marble (Plate 1, units Dgm, Dwm and Pm). Weathered surfaces range from gray or white to cream, orange or pinkish. White marble generally occurs nearer the pluton and lower in the thick marble unit. Gray marble occurs locally within the lower schist unit.

Impure, calcite marble is the most common type of marble in the area but some relatively "clean" marble can be found locally. Varieties of marble which were observed include siliceous, dolomitic and micaceous marble. Quartz is the most common accessory mineral and ranges up to about 5%. Dolomite occurs sporadically but is largely absent near the pluton due to dedolomitization and formation of calc-magnesian silicate minerals during contact metamorphism. Micaceous marbles include phlogopite-, white mica- and chlorite-bearing marbles; phlogopite is most common in the white marbles. Near the pluton these types of marbles locally grade into calc-silicate marbles which are discussed in a later section.

Marble in the study area has been thoroughly recrystallized and grain sizes are usually medium- to very coarse-grained. Extremely

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coarse-grained (marmoritized) marble occurs nearest the pluton. Granoblastic, polygonal texture is ubiquitous. White mica, phlogopite or chlorite typically define a weak foliation which parallels large-scale metamorphic layering. Deformed twin lamella in calcite can be observed in thin section.

Metamorphic structures within marble are common and generally are paralleled by mineral foliations. Most metamorphic layering appears to represent transposed sedimentary bedding. Interlayers of greenschist, quartz schist or calc-schist range up to a few meters in thickness. Relict bedding ranges from a few centimeters up to a few tens of meters in thickness. Laminations rarely exceed a few millimeters in thickness and in some areas form delicate, isoclinal folds. The most spectacular, larger scale folds in the study area are formed in marble. Relict crossbedding in marble was observed in one locality and relict sedimentary beccia or conglomerate occur sporadically. Fragmental marble occurs in one outcrop and contains blocks of marble up to a meter in thickness and may represent a relict sedimentary slump feature.

Fossil corals were collected from one locality in the uppermost portion of the thick marble unit at the north edge of the study area. One specimen is identified as a phaceloid rugose coral which could be from any Silurian to Permian system, but is more likely Silurian or Upper Devonian (Frasnian) in age (Oliver, W. A., Jr., writ. comm., 1982) (Figure 9). Another specimen is a solitary tetracoral which could be Ordovician to Permian in age

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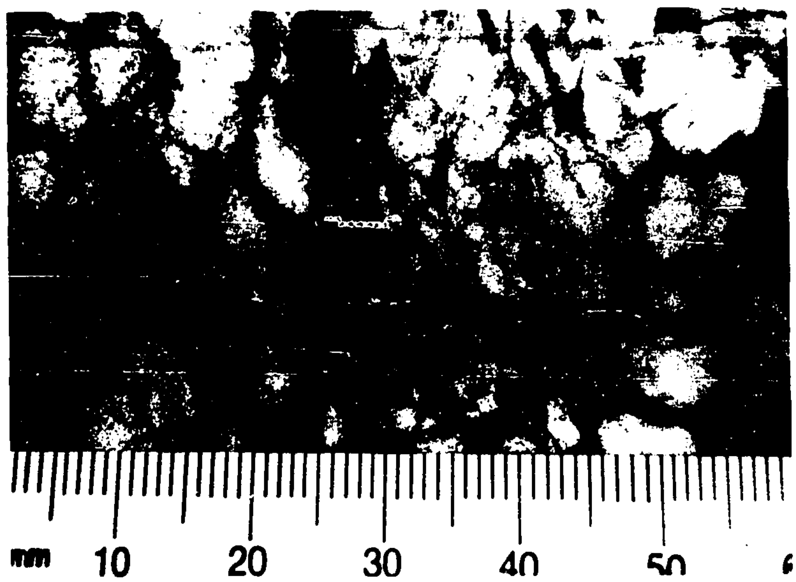

Figure 9. Photograph of specimen of phacelcid rugose coral from uppermost portion of thick marble unit in northeastern study area. Age of coral is Silurian to Permian, but is more likely to be Silurian to Upper Devonian (Frasnian) (Oliver, W. A., Jr., writ. comm., 1982).

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(Oliver W. A., Jr., writ. comm., 1982). These fossils help provide a basis for correlation of the thick marble unit with the Skajit Formation.

Calc-schist

Calc-schist is not abundant, but does occur sporadically throughout the study area. Northeast of Saddle Creek, quartz-mica calc-schist overlies and intertongues with calcite and dolomitic marble (Plate 1, unit Dmcs). In some areas calc-schist occurs as interlayers within the thick marble unit (Plate 1, unit Dqcs).

Calc-schists in the study area typically contain 30% to 60% calcite, sparse dolomite and abundant micaceous minerals. Northeast of Saddle Creek this rock type commonly consists of quartz-chlorite-white mica calc-schist with accessory dolomite. It is typically gray or greenish in color and weathers orange to brown. Calc-schists occurring as interlayers within thick marble are typically gray to buff colored and have compositions very similar to those above the marble section except near the pluton where they contain higher grade minerals such as phlogopite and tremolite (discussed in a later section).

Texturally, calc-schists are characterized by well-developed foliations defined by oriented white mica and chlorite and also by phlogopite closer to the intrusion. Relict structures commonly consist of alternating bands of coarse-grained and medium-grained calcite plus mica.

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Quartz Schist

Semipelitic, quartz schist is widely distributed in the study area (Plate 1, units Dgs, Dbs, Dggs, Pbs and Pggs). Quartz schist commonly occurs above or below the thick marble unit although quartz schist interlayers can be found within this marble unit.

Quartz schists in the study area are characterized by medium- to coarse-grain sizes and well-developed foliations. Quartz is commonly granoblastic and may have granulated or sutured grain boundaries. The primary schistosity is commonly formed by white mica+biotite±chlorite. Biotite or chloritoid are locally porphyroblastic. Garnets are commonly subidioblastic but some are xenoblastic and contain numerous inclusions which are concentrated in peripheral zones. Biotite and garnet are commonly retrograded to chlorite. Local compositional layering is largely metamorphic in origin but locally may represent relict sedimentary bedding. Coarse-grained quartz schist which contains garnet, mica or amphibole and has well-developed metamorphic layering may be referred to as paragneiss.

Low grade white mica-chlorite and chlorite-white mica quartz schist overlies or intertongues with gray marble northeast of Saddle Creek. Graphitic or calcareous horizons are also common in quartz schist of this area.

Biotite-bearing quartz schists occur both above and below the thick marble unit on north-trending ridges west of Saddle Creek. One type, chlorite-biotite-white mica-quartz schist with minor

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albite, accessory tourmaline and trace sphene, characteristically overlies the thick marble unit. A similar biotite-bearing quartz schist also underlies the thick marble unit but differs by having: 1) coarser-grain size, 2) greater abundance of biotite, plagioclase, alkali-feldspar, garnet and amphibole, 3) local interlayered quartzites, 4) thin, discontinuous zones of calc-silicate rocks, and 5) areas containing relict, clastic, carbonate material.

Garnet-bearing quartz schists crop out in areas west of Saddle Creek (Plate 1). The garnet-bearing quartz schists contain the accessory minerals white mica, chlorite and biotite. West of Arrigetch Creek they occur above the thick marble unit; in the central portions of the study area they comprise the lowest exposed unit.

Chloritoid-bearing quartz schist is not abundant and occurs locally in the northwestern study area where it overlies marble (Plate 1). It consists of quartz+white mica+chlorite+chloritoid.

Mica Schist

Pelitic mica schist is rare in the study area and typically occurs as interlayers a few meters thick in quartz schist (Plate 1, units Dms and Dqms).

Low grade, graphitic, quartz-white mica-chlorite schist crops out sporadically northeast of Saddle Creek. Graphitic, quartz-chloritoid-white mica-chlorite schist locally overlies marble in the northwestern study area (plate 1).

Garnet (almandine)-biotite-chlorite schist (Figure 10) occurs in areas south and west of Saddle Creek. Accessory minerals in

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garnet-bearing mica schist include quartz, calcite, white mica and opaque minerals. Garnet porphyroblasts, where developed, are set in a medium-grained groundmass of chlorite and biotite. Garnet is commonly sheathed and veined with chlorite.

Greenschist

Interlayers of greenschist 1.0 to 3.0 m thick occur within the thick marble unit (Plate 1, unit Dgs).

Greenschist consists primarily of actinolite with up to 10% sphene and up to 30% epidote (Fig. 11). Minor albite, chlorite, hematite, magnetite and quartz also occur. Greenschists near the intrusive contact are locally crosscut by veinlets of aplitic rock containing quartz, alkali-feldspar, hematite, spherulitic chlorite and fibrous actinolite inclusions (in quartz).

Major oxide data for greenschists are listed in Table 3. The values are comparable to those of tholeiitic basalts.

Greenschists are typically fine- to medium-grained and have well-developed foliations. Foliations are formed by oriented actinolite and epidote or chlorite. Sphene forms xenoblasts which are elongate parallel to the foliation. Progressing southward towards the intrusion the foliations become less evident and hornfelsic textures become apparent. One sample from near the intrusion contains some random, idioblastic amphibole and epidote.

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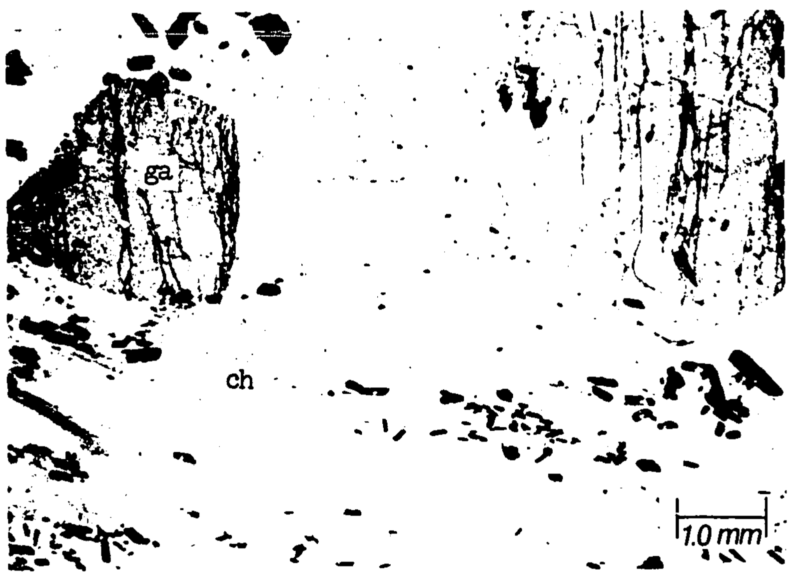

Figure 10. Photomicrograph of thin section of pelitic, garnet-biotite-chlorite schist. This lithology occurs locally in the study area to the south and west of Sadale Creek.

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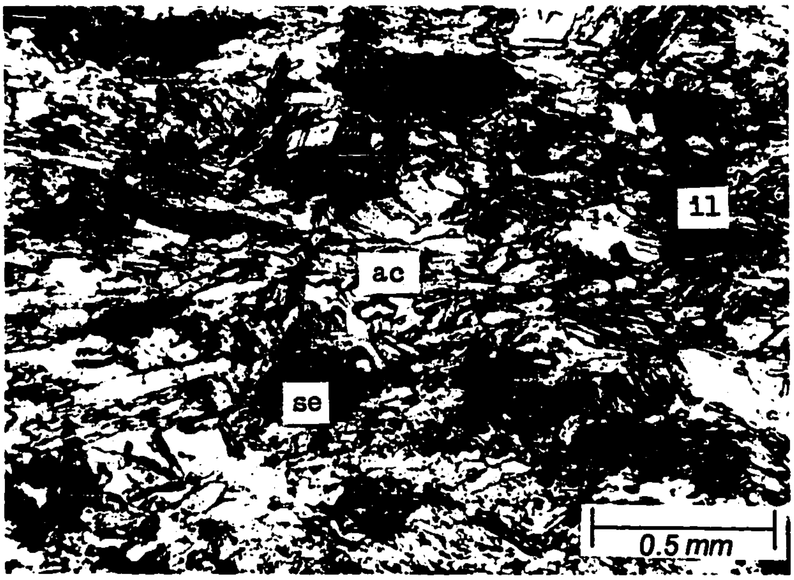

Figure 11. Photomicrograph of thin section of sphene-actinolite greenschist. Sphene is xenoblastic and elongate parallel to foliation defined by actinolite.

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Table 3

Whole Rock Major Oxide Data (in Weight Percent) of Greenschists

Values determined by X-ray fluorescence spectrometry except for FeO (determined by volumetric chemical analysis).

Sample	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	LOI	H_2O-	Total
1	47.66	14.72	1.94	12.22	4.98	10.54	2.62	0.96	2.80	0.24	0.24	0.66	0.50	100.08
2	48.90	13.87	1.08	10.59	8.23	9.74	1.96	0.23	1.84	0.16	0.16	2.42	0.33	99.51
3	44.71	12.53	4.03	8.13	7.51	15.51	0.58	0.31	1.88	0.21	0.18	1.67	0.49	97.74

Samples 1 and 2: actinolite greenschist
Sample: epidote-actinolite greenschist

Regional Metamorphism

Regional metamorphic rocks which occur in the study area include orthogneiss, marble, calc-schist, quartz schist, mica schist and greenschist. Foliations formed by micas are well-developed in these rocks and have similar orientations suggesting they were formed in response to pervasive regional metamorphism. Hornfels are well-preserved in the contact-metamorphic zone where foliations are absent and only local, semipenetrative cleavages can be found. Foliations were not formed in these rocks apparently because of their dehydrated bulk compositions which prevented the growth of mica or amphibole.

Mineral assemblages found in semipelitic metasediments and mafic metavolcanics in the study area provide an indication of regional metamorphic grade which generally decreases northward from upper to lower greenschist facies. Northeast of the Saddle Creek area semipelitic rocks typically contain the assemblage chlorite+white mica+quartz, which is a charactertistic assemblage of "chlorite zone" rocks in many areas of low-grade or greenschist facies regional metamorphism (Zen, 1960 and Turner, 1981). Semipelitic to pelitic rocks found south and west of the Saddle Creek area commonly contain the assemblages almandine+chlorite+biotite+white mica+quartz or biotite+chlorite+white mica+quartz. The assemblage almadine+chlorite+biotite+white mica+quartz is very typical of the Dalradian "almadine zone", which is widely interpreted to indicate a zone of transition from the greenschist to amphibolite facies (Barrow, 1893 and Atherton,

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1964). The presence of almadine in these lithologies also suggests high pressure greenschist facies metamorphism (Miyashiro, 1953 and Winkler, 1976). Since garnet occurs only south and west of the Saddle Creek area (Plate 1) a garnet isograd exists there.

The assemblage chloritoid+chlorite+white mica+quartz occurs only in pelitic metasediments in a few localities northwest of Watchtower Ridge. Chloritoid is stable into the "garnet zone" of the greenschist facies but breaks down in the amphibolite facies to form staurolite (Atherton, 1964 and Albee, 1972).

Greenschist in the study area contains the assemblage actinolite+clinozoisite+epidote+albite+sphene±chlorite±biotite. This assemblage is characteristic of greenschist facies metamorphism; in the amphibolite facies actinolite and albite are replaced by hornblende and oligoclase (respectively) (Turner, 1981).

Mineral assemblages and textures found in the granite orthogneiss suggest extensive recrystallization and similar grades of metamorphism as most of the country rocks in the study area to the north. Garnet, although not abundant, does occur as a metamorphic mineral in the orthogneiss. The alteration of plagioclase to epidote or clinozoisite is common. Biotite and white mica, which are thoroughly recrystallized in the primary foliation of the orthogneiss, have Cretaceous K-Ar radiometric ages (Turner and others, 1979 and Dillon and others, 1980a). The assemblage garnet+epidote+clinozoisite+biotite+white mica is generally accepted to indicate upper greenschist facies metamorphism (Turner, 1981). Retrograde alteration

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of biotite to combinations of chlorite and sphene is suggestive of late stage metamorphism of the plutonic rocks in the lower greenschist facies as it was in the garnet zone metasediments further north.

Regional radiometric, stratigraphic, fossil and mineralogical evidence supports the hypothesis of at least three metamorphic events in the central and southern Brooks Range. Evidence for a major orogeny in the middle to late Mesozoic is primarily drawn from the numerous Cretaceous K-Ar ages from gneiss and schist of the southcentral Brooks Range (Turner and others, 1979) from discordant zircon ages (Dillon and others, 1980a), from multiple metamorphic overprints on Middle and Upper Paleozoic rocks (Dillon, J. T., pers. comm., 1982) and from stratigraphic and structural evidence for northward overthrusting of Mississippian to Triassic (?) oceanic rocks onto the Brooks Range (Newman and others, 1977, Patton and others, 1977, Roeder and Mull, 1978 and Dillon and others, 1979). Dillon and others (1981) describe Proterozoic (?) and Upper Devonian rocks in the Wiseman quadrangle having a primary schistosity which is disrupted by a younger, semipenetrative cleavage. These suggest that two post-Upper Devonian regional metamorphic events are probably related to mid-Mesozoic orogeny. Contact-metamorphism resulted from the intrusion of granitic plutons during a major mid-Paleozoic orogeny (Dillon and others, 1980a). A pre-Late Devonian regional metamorphic event is suggested by the "great structural complexity" seen in Proterozoic(?), polymetamorphic banded schists of the southern

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Brooks Range, by intrusion of these schists by the Upper Devonian Wild River pluton (Dillon and others, 1981) and by Proterozoic radiometric ages in the southern Brooks Range (Turner and others, 1979).

The regional metamorphic history of the study area is still not well understood. However, several lines of evidence support the occurrence of at least one Mesozoic, upper greenschist facies metamorphic event that recrystallized much of the granite pluton and formed foliations defined by oriented micas. This event was probably responsible for the northward decreasing metamorphic gradient which is common along this latitude and northward in the Brooks Range (Grybeck and others, 1977). Widespread chloritization in the pluton and adjacent country rocks indicates that the latest stage of Mesozoic metamorphism was in the lower greenschist facies. Some evidence such as local helicitic textures in hornfels is consistent with deformation prior to or during emplacement of the pluton. Previously cited evidence for a moderate depth of emplacement of the pluton could favor the hypothesis of synmetamorphic intrusion or of a Devonian regional metamorphic event.

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CONTACT-METAMORPHIC ROCKS

Introduction

Contact-metamorphic rocks along the northern contact of the Arrigetch Peaks pluton (Plate 1, unit Dh) are extremely well preserved. Hornfels are very commonly found in a zone at least a few meters thick between impure marble and orthogneiss. Hornfels are those rocks generally composed of fine- or coarse-grained randomly oriented calc-silicate minerals (Spry, 1969). Calc-silicate marbles generally contain 10% to 50% calc-silicates and occur outboard from the hornfels zone.

Mineral zones in metamorphosed carbonate rocks are present in some areas. Hornblende-hornfels facies and albite-epidote hornfels facies minerals were formed during prograde contact-metamorphism.

Contact-metamorphic reactions were influenced by bulk composition, temperature, total fluid pressure and the partial pressures of CO_2 and H_2O. Prograde contact-metamorphic reactions in the subsystems $CaO\text{-}MgO\text{-}SiO_2\text{-}H_2O\text{-}CO_2$ and $CaO\text{-}Al_2O_3\text{-}SiO_2\text{-}H_2O\text{-}CO_2\text{-}K_2O$ can be recognized. Retrograde reactions can be recognized locally.

Hornfels

Hornfels form a near-continuous zone adjacent to the northern pluton contact (Plate 1, unit Dh). This zone is roughly parallel to the intrusive contact and commonly ranges from a few meters to a few tens of meters in thickness. Hornfels typically have sharp

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contacts with orthogneiss but contacts with outlying calc-silicate marbles are largely gradational. Hornfelsed inclusions occur locally in marginal portions of the granite orthogneiss. Banded hornfels are common in the hornfels zone. The bands probably represent relict sedimentary or metamorphic structures. Plastic deformation is indicated by complex folding of the bands.

Calc-silicate and calcareous hornfels are commonly comprised of calc-silicate minerals, mica, calcite, quartz and feldspar in varying proportions. Calcic clinopyroxene, the most common mineral, generally lacks pleochroism which suggests it is diopsidic. Pale isotropic, presumably grossularitic (?) garnet is also very common. Amphibole (tremolite-actinolite) is less common. Wollastonite, idocrase, biotite, plagioclase, calcite, quartz and alkali-feldspar occur as minor or accessory minerals. In some areas amphibole is altered to pyroxene but locally is retrograde after pyroxene. Other retrograde minerals include chlorite, epidote, clinozoisite, zoisite and white mica. Banded hornfels consist of alternating calc-silicate- and calcite-rich layers (Figure 12) or consist entirely of layers enriched in differing calc-silicate minerals such as pyroxene or idocrase.

Fine- to coarse-grained, hornfelsic textures are well-developed in the calc-silicate and calcareous hornfels. These textures are best developed within the first several meters of the intrusive contact and grade into strongly foliated rocks with distance from it. Where calcite is abundant, a granoblastic polygonal texture

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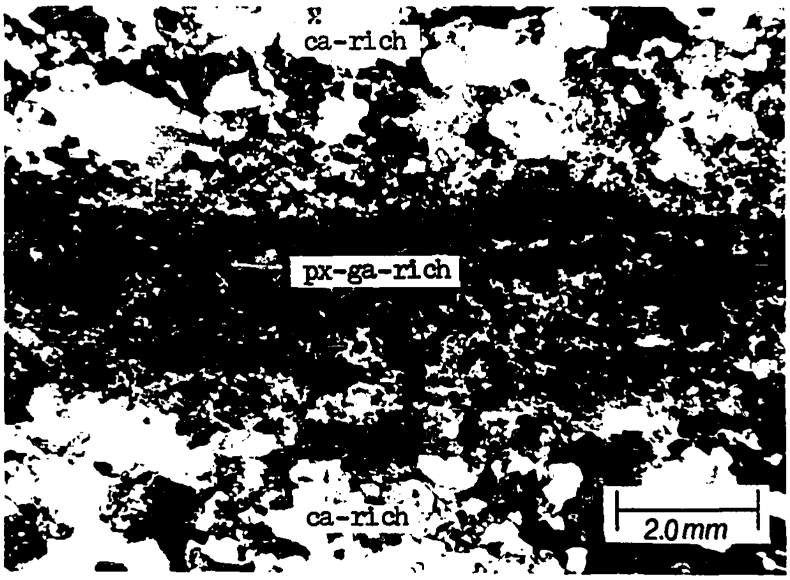

Figure 12. Photomicrograph of thin section of banded calcareous hornfels found near base of Night Ridge. Bands consist of alternating calcite-rich and pyroxene- garnet-rich layers.

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is well-developed. Calc-silicate minerals locally form along calcite grain boundaries.

Pelitic hornfels are not abundant, but were noted in two localities where they occur within approximately 20 m of the intrusive contact. In one locality near Oz Creek pelitic hornfels consist of biotite+garnet (almandine ?)+plagioclase+magnetite (Figure 13). Retrograde chlorite and siderite are also seen in this sample.

Poikiloblastic textures are common in pelitic hornfels. Garnet or plagioclase are locally helicitic and contain deformed layers of inclusions of opaques, quartz or feldspar. Garnet in pelitic hornfels locally has overgrowths and anisotropic zones.

Calc-Silicate Marble

Calc-silicate marble typically crops out adjacent to hornfels but further from the intrusion. Contacts of calc-silicate marble with hornfels are either abrupt or gradational. Textures and structures of calc-silicate marble are very similar to those of lower grade marble discussed previously.

Calc-silicate marble is composed of calcic to calc-magnesian assemblages; higher temperature assemblages occur closer to the intrusive contact. The highest grade mineral assemblage observed in calc-silicate marble is calcite+garnet+pyroxene+wollastonite+idocrase (Figure 14). Lower grade mineral assemblages include calcite+quartz+plagioclase±white mica±chlorite (Figure 15)

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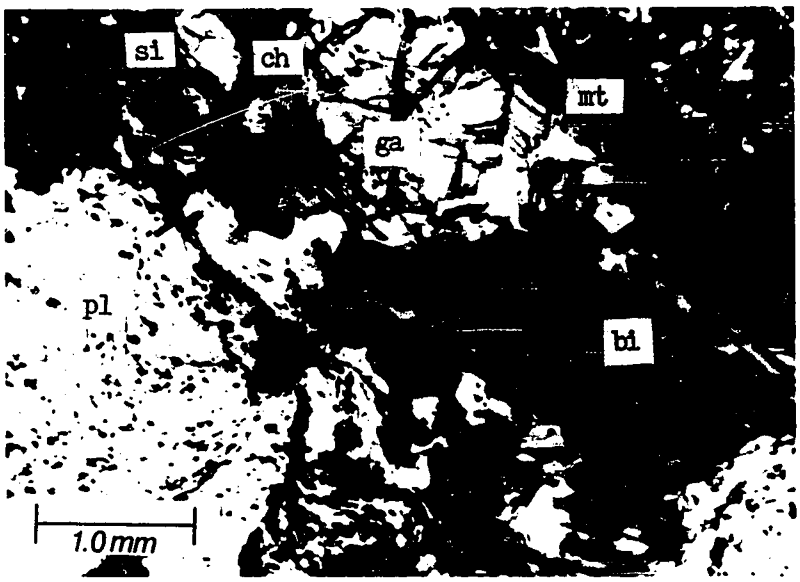

Figure 13. Photomicrograph of thin section of pelitic, plagioclase-garnet-biotite hornfels. Chlorite and siderite occur as retrograde minerals. Helicitic texture is seen as deformed layers of opaque inclusions in garnet and plagioclase.

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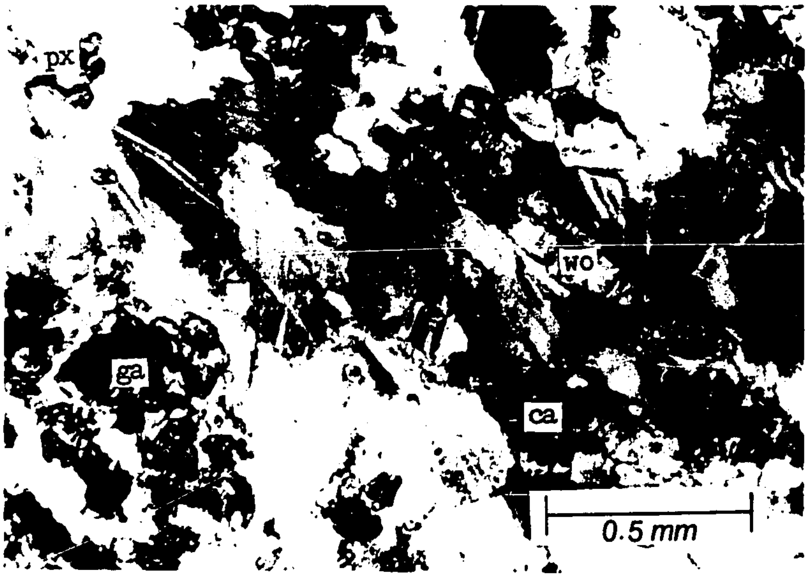

Figure 14. Photomicrograph of thin section of wollastonite-pyroxene-garnet-calcite marble found on Night Ridge. This marble occurs adjacent to garnet-pyroxene hornfels near the intrusion and is found in mineral zone I (discussed in next section).

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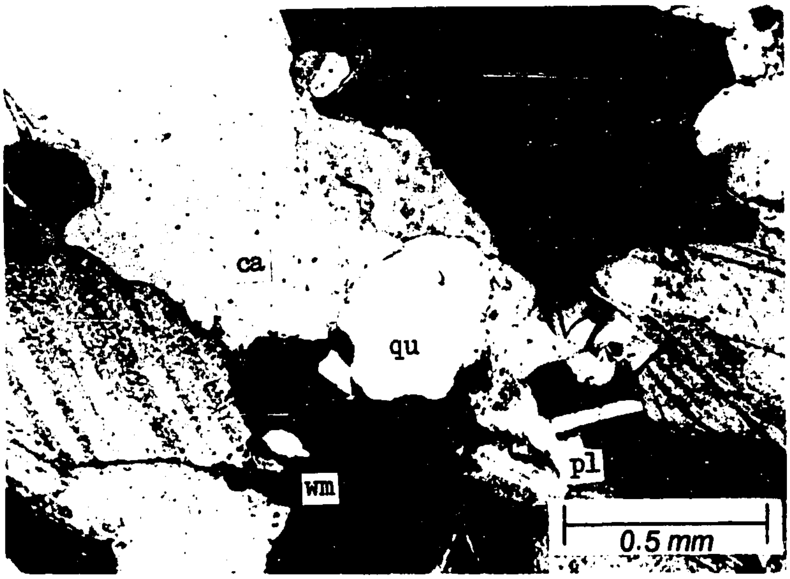

Figure 15. Photomicrograph of thin section of plagioclase-quartz-calcite marble found on Night Ridge. White mica and chlorite occur as alteration minerals; white mica locally pseudomorphs plagioclase. Composition of plagioclase ranges from andesine to albite (An 35 to An 10). This marble is found in mineral zone II (discussed in next section). The assemblage calcite + quartz + plagioclase represents the lower temperature equivalent of the assemblage calcite + garnet + wollastonite.

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and calcite+tremolite+phlogopite+quartz±alkali-feldspar±white mica±chlorite (Figure 16).

Plagioclase is locally altered to calcite, white mica and/or chlorite; tremolite and phlogopite are locally altered to calcite, chlorite, alkali-feldspar and/or sphene. Clinozoisite and epidote are found locally.

Textures of calc-silicate marble are typically very coarse-grained. Tremolite occurs as fascicular bundles which lie within the plane of foliation. Foliations formed by phlogopite or white mica tend to parallel large-scale metamorphic layering. Compositional layering is probably transposed bedding and is commonly isoclinally folded. Relict sedimentary structures are rarely preserved.

Contact-Metamorphism

Contact-metamorphic reactions which formed mineral zones in carbonate rocks on Night Ridge (Figure 17) were applied to published phase equilibria data relating temperature (T), total fluid pressure and mole fraction CO_2 (X_{CO_2}). The approximate temperature of contact-metamorphism in each zone can be inferred if total fluid pressure and X_{CO_2} are assumed.

The total fluid pressure, if assumed equal to the lithostatic pressure, can be estimated from the stratigraphic thickness of Devonian rocks in the region. Since 1.5 kilobars (kb) total fluid pressure corresponds to the possible minimum total thickness during intrusion (discussed previously), 2 kb total fluid pressure is

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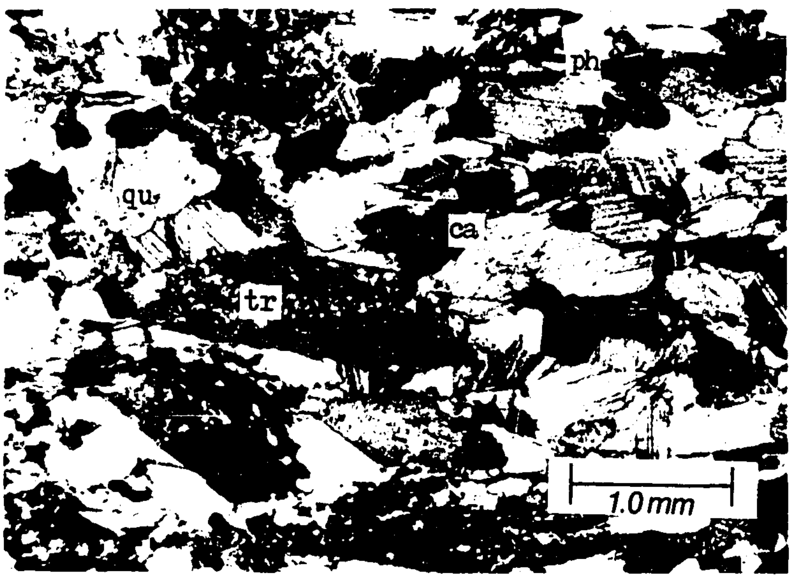

Figure 16. Photomicrograph of thin section of phlogopite-tremolite-calcite marble found on Night Ridge. Tremolite is locally altered to chlorite and phlogopite is locally altered to chlorite or tremolite and alkali-feldspar. This marble is found in mineral zone III (discussed in next section). Near the intrusion the assemblage tremolite + calcite + quartz is replaced by pyroxene.

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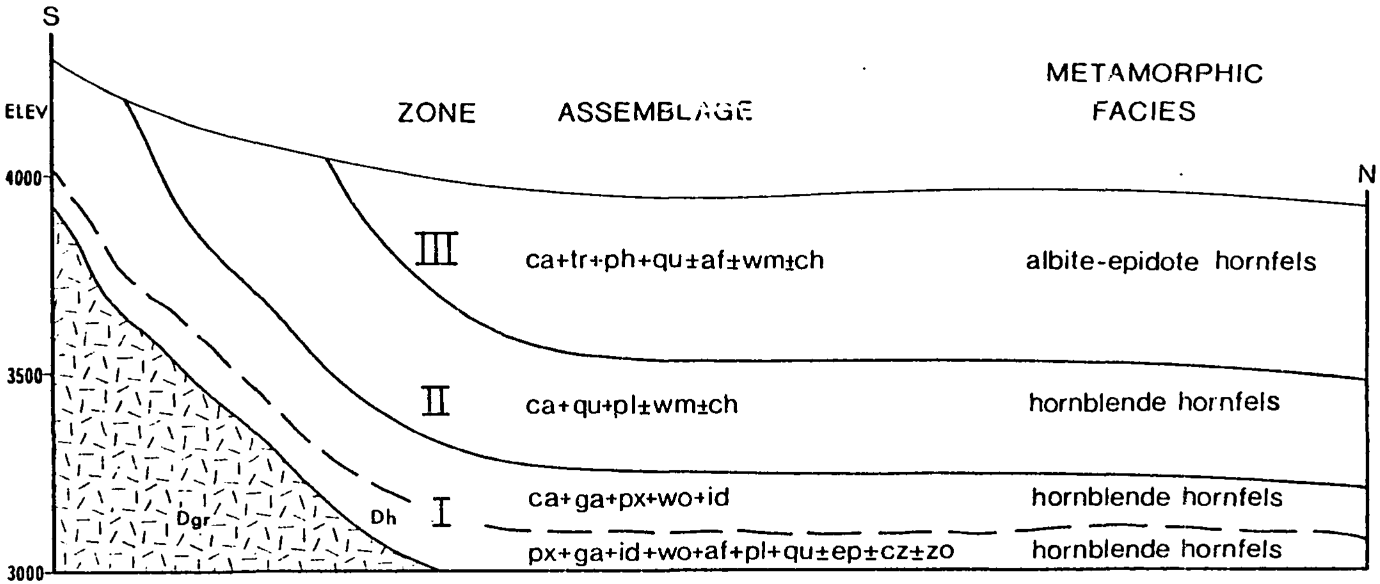

Figure 17. Schematic cross-section of mineral zones found in metamorphosed carbonate rocks on Night Ridge. Boundaries of zones approximated. Protoliths of zones I and II contained more marly impurities than the protolith of zone III. Dgr = orthogneiss; Dh = hornfels.

assumed in order to interpret phase equilibria diagrams. Low values of X_{CO_2}, generally ranging from .1 to .2, are typical in this setting (Enaudi and others, 1980).

The mineralogy of each zone was also determined by the bulk composition of the protolith. Some of the bulk compositions can be described using the systems CaO-MgO-SiO_2-H_2O-CO_2 and CaO-MgO-Al_2O_3-K_2O-H_2O-CO_2. Phase relations and metamorphic reactions which can be represented by these systems are shown in Figure 18. Other bulk compositions can be described using the system CaO-Al_2O_3-SiO_2-H_2O-CO_2. Phase relations and reactions which can be represented by this system are shown in Figure 19. Protoliths of zones I and II contained more marly impurities than the protolith of zone III.

Hornfels in Oz Creek are contrasted with those on Night Ridge. The Oz Creek hornfels are of slightly lower metamorphic grade due to lower temperatures or higher X_{CO_2} conditions in the Oz Creek area.

Zone I

Zone I consists of hornfels and calc-silicate marble near the intrusive contact. Zone I is characterized by the presence of diopsidic pyroxene, grossularitic garnet and wollastonite in these rocks.

The following reactions commonly form diopside, grossular garnet and wollastonite (respectively) in this type of environment:

$$1 \text{ tremolite} + 3 \text{ calcite} + 2 \text{ quartz} \rightarrow 5 \text{ diopside} + 3\ CO_2 + 1\ H_2O \quad (1)$$

$$1 \text{ plagioclase} + 2 \text{ calcite} + 1 \text{ quartz} \rightarrow 1 \text{ grossular} + 2\ CO_2 \quad (2)$$

$$1 \text{ calcite} + 1 \text{ quartz} \rightarrow \text{wollastonite} + 1\ CO_2 \quad (3).$$

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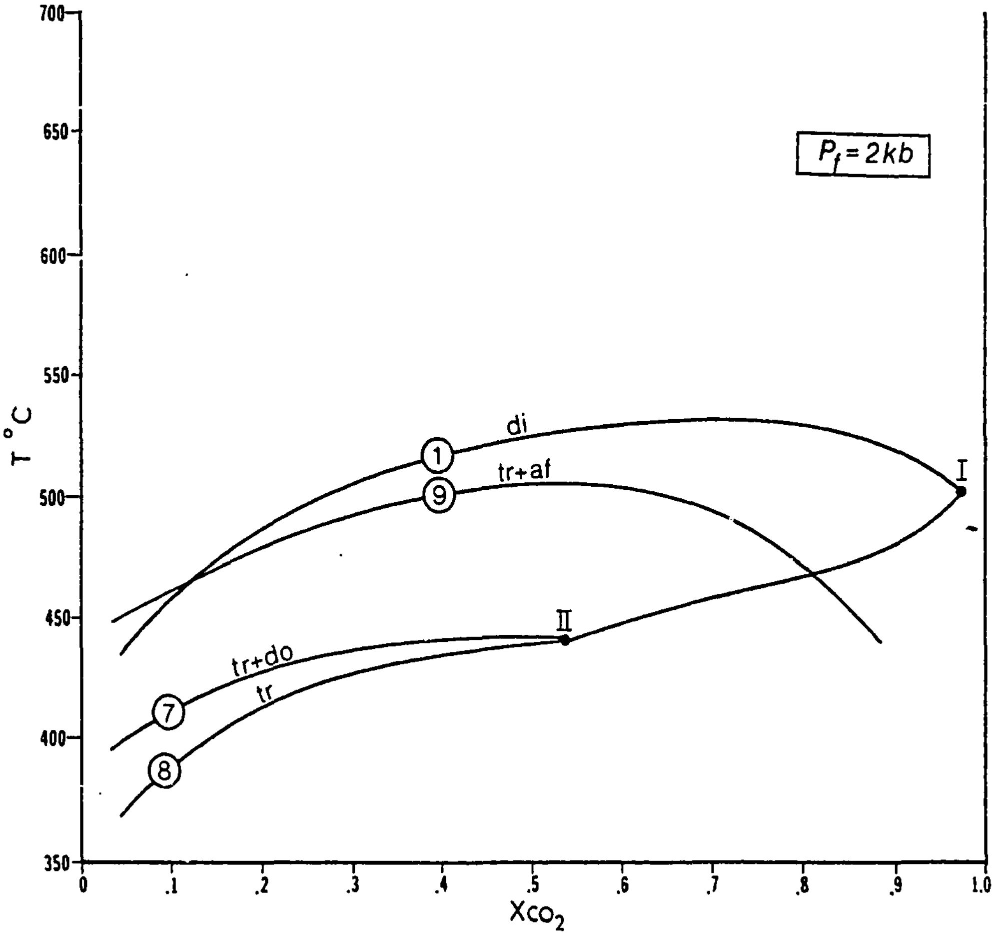

Figure 18. Isobaric T-X_{CO_2} diagram at 2 kb total fluid pressure indicating phase relations and reactions in the system CaO-MgO-SiO_2-H_2O-CO_2 (reactions 1, 7 and 8). Curve for reaction 9 applies to the system CaO-MgO-Al_2O_3-K_2O-H_2O-CO_2 and is superimposed. Reactions for the numbered curves are:

1tr + 3ca + 2qu → 5di + 3CO_2 + 1H_2O (1)
1ta + 3ca → 1tr + 1do + 1CO_2 + 2H_2O (7)
5ta + 6ca + 4qu → 3tr + 6CO_2 + 2H_2O (8)
5ph + 6ca + 24qu → 3tr + 5af + 2H_2O + 6CO_2 (9).

Reaction curves 1, 7 and 8 from Slaughter and others (1975) and reaction curve 9 from the data of Hewitt (1976). Curve 1 should be shifted up for solid solution of Fe^{2+} in amphibole, or shifted down for solid solution of Fe^{2+} in pyroxene. Mineral abbreviations given in Table 1; P_f = total fluid pressure.

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Figure 19. Isobaric T-X_{CO_2} diagram at 2 kb total fluid pressure indicating phase relations and reactions in the system CaO-Al_2O_3-SiO_2-H_2O-CO_2. Reactions for the numbered curves are:

$$1\ gr + 2\ CO_2 \rightarrow 1\ an + 2\ ca + 1\ qu \tag{2}$$

$$1\ ca + 1\ qu \rightarrow 1\ wo + 1\ CO_2 \tag{3}$$

$$2\ zo + 5\ ca + 3\ qu \rightarrow 3\ gr + 5\ CO_2 + 1\ H_2O \tag{4}$$

$$5\ pr \rightarrow 2\ zo + 2\ gr + 3\ qu + 4\ H_2O \tag{5}$$

$$2\ zo + 1\ CO_2 \rightarrow 1\ ca + 3\ an + 1\ H_2O \tag{6}.$$

Reaction curves taken from Winkler (1976). Location of invariant point III approximated from the upper temperature limit of prehnite stability (approximately 405°C) at 2 kb total fluid pressure with respect to reaction (5) (Liou, 1971). Reaction curves 2 and 3 should be adjusted up or to the left for increasing albite component in plagioclase; plagioclase composition in zone II ranges from andesine to albite (An 35 to An 10). Mineral abbreviations given in Table 1; P_f = total fluid pressure.

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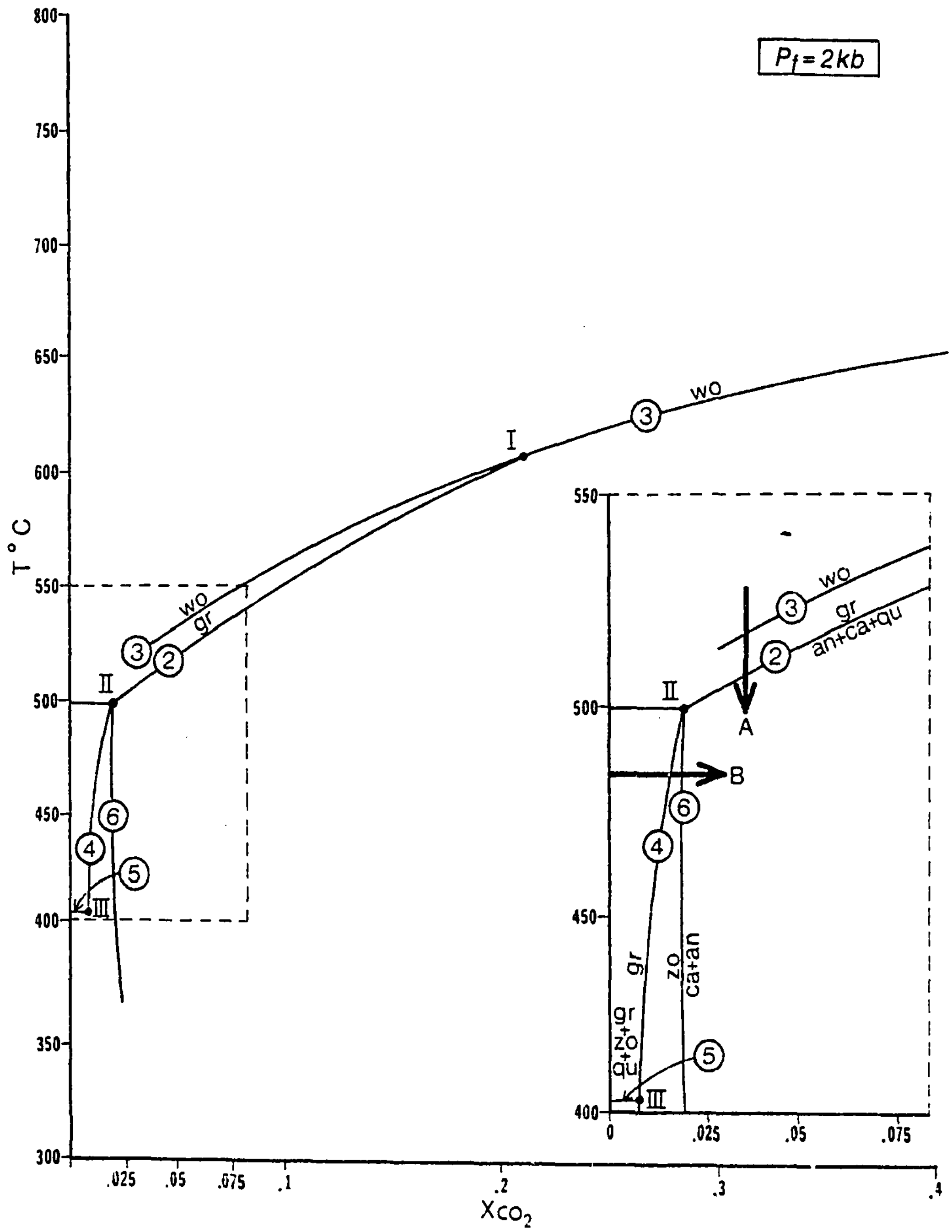

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Reaction (1) is represented by reaction curve 1 in the T-X_{CO_2} diagram of Figure 18. Reactions (2) and (3) are represented by reaction curves 2 and 3 of the T-X_{CO_2} diagram in Figure 19. The position of reaction curve 1 indicates a minimum temperature of approximately 460°C was required to form diopside if the X_{CO_2} was approximately .1. However, the positions of reaction curves 2 and 3 indicate that substantially higher temperatures were present in zone I. Grossular garnet and wollastonite required a minimum temperature of 500°C to form if the X_{CO_2} was above .025. Grossular garnet could form at temperatures below 500°C by the dehydration of zoisite or prehnite (reactions (4) and (5), respectively, Figure 19) only if the X_{CO_2} was extremely low (less than .025).

Zone II

Zone II consists of calc-silicate marble which occurs further from the intrusion than zone I. The characteristic assemblage of zone II is calcite+quartz+plagioclase. The composition of plagioclase in zone II ranges from andesine to albite (An 35 to An 10). Clinozoisite and zoisite occur locally in calc-silicate marble in this area.

Plagioclase typically forms in marly carbonates by the dehydration of zoisite or clinozoisite according to the reaction:

$$2 \text{ zoisite} + 1\ CO_2 \rightarrow 1 \text{ calcite} + 3 \text{ plagioclase} + 1\ H_2O \qquad (6).$$

Reaction (6) is represented by reaction curve 6 in the T-X_{CO_2} diagram of Figure 19. Reaction curve 6 does not place constraints

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on the temperature of formation of plagioclase, however the position of this curve does indicate that the X_{CO_2} in zone II was above about .025. The bulk composition of plagioclase-bearing marble in zone II is similar to that of garnet-wollastonite-bearing marble in zone I. Increasing reaction of carbonate closer to the intrustion should favor a higher X_{CO_2} in zone I than in zone II. Hence, the absence of garnet and wollastonite in zone II is most likely the result of an outward decreasing thermal gradient (path A, Figure 19 inset) rather than of an isothermal gradient in X_{CO_2} (path B, Figure 19 inset).

Zone III

Zone III consists of calc-silicate marble which occurs further from the intrusion than zone II and is characterized by the presence of tremolite. Zone III also contains phlogopite which is locally altered to tremolite and alkali-feldspar (Figure 20).

At low X_{CO_2} conditions tremolite can form at low temperatures by either of the reactions:

$$2 \text{ talc} + 3 \text{ calcite} \rightarrow 1 \text{ tremolite} + 1 \text{ dolomite} + 1\ CO_2 + 2\ H_2O \quad (7)$$

or

$$5 \text{ talc} + 6 \text{ calcite} + 4 \text{ quartz} \rightarrow 3 \text{ tremolite} + 6\ CO_2 + 2\ H_2O \quad (8).$$

Phlogopite commonly forms by the reaction of dolomite with muscovite (illite) (Yoder and Eugster, 1954). Phlogopite in quartz-calc-schist in zone III is locally altered to tremolite and alkali-feldspar by the reaction:

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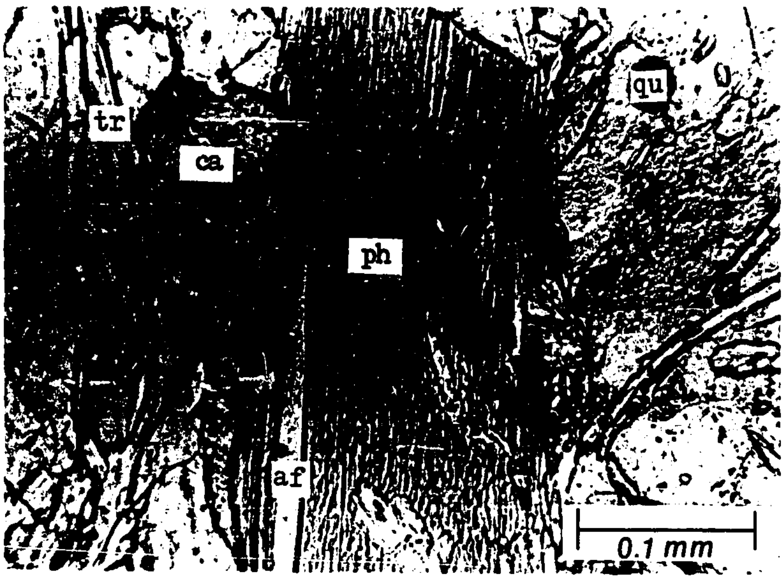

Figure 20. Photomicrograph of thin section of tremolite-phlogopite-quartz-calc-schist found on Night Ridge. Phlogopite is locally altered to tremolite and alkali-feldspar (reaction (9)). The presence of the phases phlogopite, calcite, quartz, tremolite and alkali-feldspar in textural equilibrium indicates reaction (9) did not proceed to completion.

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5 phlogopite + 6 calcite + 24 quartz → 3 tremolite + 5 alkali-feldspar + 2 H_2O + 6 CO_2 (9).

The presence of all five solid phases of reaction (9) in textural equilibrium indicates this reaction did not proceed to completion.

Reactions (7), (8) and (9) are represented by reaction curves 7, 8 and 9 (respectively) in the T-X_{CO_2} diagram of Figure 18. Quartz is commonly available in marble of zone III so minimum temperatures of formation of tremolite are defined by reaction curve 8. The position of this curve indicates that a minimum temperature of 380°C was required to form tremolite if the X_{CO_2} was greater than or equal to .1. However, the position of reaction curve 9 indicates that temperatures in portions of zone III were much higher than those which are indicated by reaction curve 8. Reaction curve 9 intersects reaction curve 1 at an X_{CO_2} value of about .12. Since diopside is absent in zone III the X_{CO_2} was apparently above .12. This relation indicates that a minimum temperature of about 470°C was required to initiate reaction (9) in zone III.

Oz Creek Hornfels

Hornfels in Oz Creek contain amphibole (tremolite-actinolite), diopsidic pyroxene, calcite and quartz (Figure 21). Amphibole is commonly seen in some stage of prograde alteration to pyroxene.

The assemblages in the Oz Creek hornfels can be interpreted with respect to reaction 1 (Figure 18). Hornfels nearest the intrusion contain the three phase assemblages pyroxene+calcite+quartz

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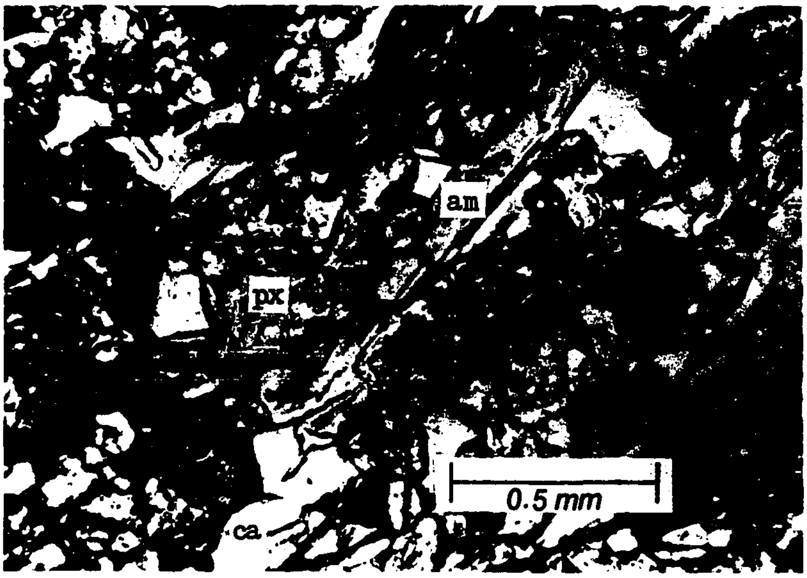

Figure 21. Photomicrograph of thin section of amphibole-pyroxene hornfels found in Oz Creek near the intrusion. The three phase assemblages seen are pyroxene + calcite + quartz and pyroxene + amphibole + quartz indicating reaction (1) proceeded until one or more of the reactants were exhausted. Further from the intrusion the four phase assemblage pyroxene + amphibole + calcite + quartz is seen indicating reaction (1) did not proceed to completion due to a lower temperature or a higher X_{CO_2}.

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and pyroxene+amphibole+quartz. These assemblages formed because reaction 1 proceeded until one or more of the reactants were exhausted. However, further from the intrusion the four phase assemblage pyroxene+amphibole+calcite+quartz can be seen. Although the constituents needed to form pyroxene were present, a lower temperature or a higher X_{CO_2} prevented reaction (1) from proceeding to completion.

The Oz Creek hornfels have a bulk composition similar to those on Night Ridge and are about the same distance from the intrusion. The presence of amphibole and pyroxene in textural equilibrium in the Oz Creek hornfels indicates that the thermal gradient was lower or the X_{CO_2} was higher than in the hornfels on Night Ridge. If the X_{CO_2} was less than about .25 the maximum temperature attained in the Oz Creek hornfels was approximately 500°C.

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CONTACT-METASOMATIC ROCKS

Introduction

Contact-metasomatic rocks in the study area include skarns and veins. Skarn occurrences are rather restricted and hence are not economically significant. Skarns or veins typically occur in calc-silicate hornfels; veins locally crosscut marble. Skarns are distinguished from hornfels by their low number of phases, absence of mineral inclusions, coarse-grain size, absence of bedform structures and podiform morphology.

During metasomatism any of the components CaO, MgO, SiO_2, Al_2O_3, K_2O, FeO, TiO_2, H_2O or CO_2 were present. Locally, more exotic constituents such as fluorine, beryllium, boron and chlorine were involved. The presence of a wide variety of components in vein deposits indicates that vein systems were open and very complex.

Assays of samples of skarn- or vein-related mineralization are reported in Table 4. These data indicate that copper and zinc are locally anomalous. Tin is anomalous in two samples of garnet skarn.

Skarns

Skarns occur locally in the northern contact zone of the Arrigetch Peaks pluton (Plate 1). They typically occur as isolated pods or lenses .1 m to 2.0 m in thickness. The protoliths were either marble or calcareous horizons in hornfels. Compositions of individual skarns are quite variable and were determined by

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Table 4

Assay Values for Skarn and Vein Samples; Results Reported in PPM
(or Weight Percent Where Indicated by "%")

Values determined by atomic absorption spectrometry.

Sample	Mineral Assemblage	Cu	Pb	Zn	Au	Ag	Mo	Sb	Sn	W
Skarns										
801D186	ac+cp+py	2270	220	8600	.01	2.09	0.01	0.01	---	---
801Ad137	ac+cp	2929	8	199	.01	0.7	2.00	1.00	---	---
81Ad123	py+cp+sp	3030	5	71	.01	0.6	1.00	1.00	---	---
81Ad142	ga+ac+cp+py+mt	1003	99	1460	.01	0.8	2.00	1.00	940	40
81Ad143	ga+ac+cp+py+mt	2.03%	183	4626	.01	11.5	3.00	23.00	1850	56
Veins										
80Ad195	gu+ch+si+gl	120	1.3%	770	.01	46.92	0.01	0.01	---	---
80Ad208	ca+qu+ac+sp+gl	160	6680	22.5%	.01	229.10	0.01	0.01	---	---

local temperature, bulk composition and fluid composition. Most skarns are comprised of calc-silicates and/or magnetite and some contain traces of sulfides.

Skarns near Oz Creek occur as isolated zones within amphibole-pyroxene hornfels (Figure 22). These skarns consist of clinozoisite+ tremolite and lesser pyroxene (Figure 23). Minor amounts of calcite, biotite, chlorite and alkali-feldspar occur and plagioclase is found in late veins.

Near Armadillo Peak a small skarn zone consisting of scapolite+ garnet replaces calcareous pyroxene hornfels. Scapolite is altered to clinozoisite or calcite.

Small outcrops of andradite garnet skarn are found in one locality near Saddle Creek. Minor amounts of magnetite also occur at this locality. Late, crosscutting veins of amphibole contain some chalcopyrite. Tin is anomalous in this skarn but no cassiterite was observed (Table 4); the tin is apparently present in garnet as skarn garnets are commonly tin-bearing (Enaudi and others, 1980).

Near Caliban some large inclusions of marble in orthogneiss contain local biotite-amphibole or pyroxene-garnet skarn. One sample of fluorite-magnetite ribbon skarn was found in this area.

Scattered occurrences of magnetite skarn are found throughout the study area. The magnetite typically occurs as pods in marble (Figure 24). Minor amounts of garnet or epidote occur in these magnetite pods; disseminated magnetite is found locally in calc-silicate skarn.

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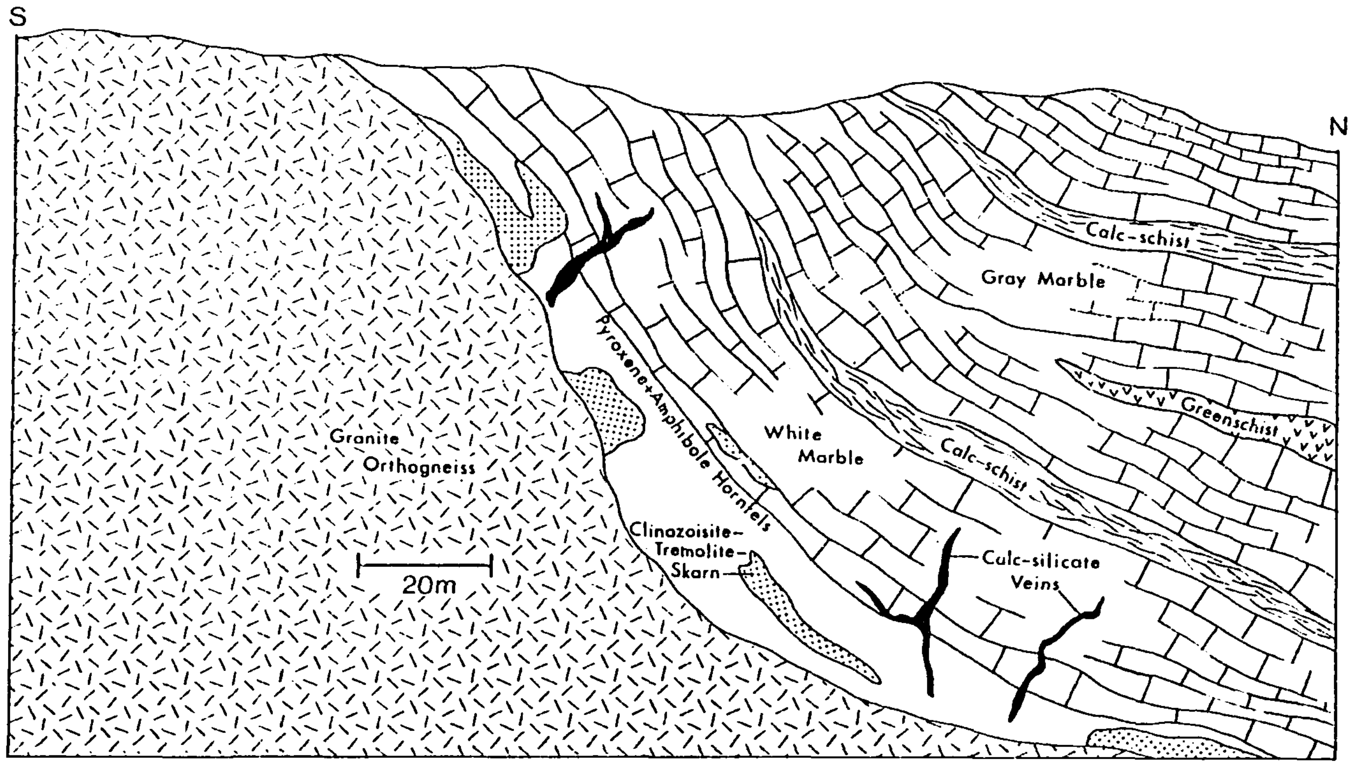

Figure 22. Schematic cross-section of tremolite-clinozoisite skarn zones (dotted pattern) replacing calcareous amphibole-pyroxene hornfels near Oz Creek. Calc-silicate veins (shaded) crosscut hornfels and extend into adjacent marble.

An outcrop of pyroxene-rich skarn or endoskarn was found near Eden Creek. This rock contains abundant sphene which is altered to magnetite and salitic pyroxene. Small-scale dikes (.1 mm in thickness) of aplitic material can be seen in thin section.

Skarn textures are very coarse-grained with grain sizes ranging from 1.0 mm to 3.0 mm and larger. Clinozoisite and scapolite locally contain optical zoning apparently due to compositional variations. Polysynthetic twinning is common in clinozoisite and scapolite. Tremolite replaces and locally pseudomorphs pyroxene. Alkali-feldspar and plagioclase typically occur in intergranular areas and veins. Foliations and bedform structures are absent in skarns.

Veins

Veins .01 to 0.2 m thick are common in the northern zone of the Arrigetch Peaks pluton (Plate 1). These typically consist of low temperature calc-silicate minerals and some are associated with sulfide mineralization (Table 4).

Several types of veins occur in the Oz Creek vicinity of the contact zone. One vein deposit in marble consists of the following minerals: calcite, siderite, phlogopite, white mica, clinochlore, plagioclse, alkali-feldspar (adularia ?) and rutile. The rutile is present in nodular siderite and calcite and forms some metacrysts up to 1.5 cm in length (Figure 25). Clinochlore forms fine-grained, spherulitic overgrowths on other minerals of the vein. One quartz

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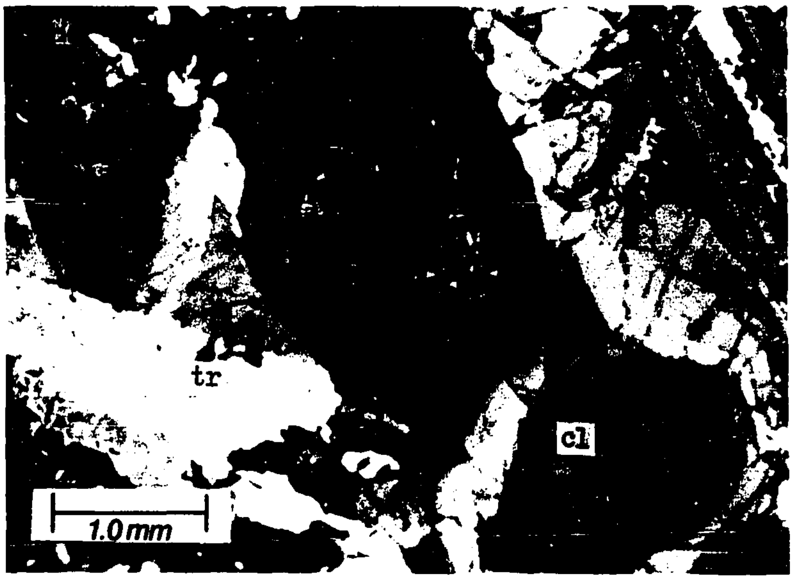

Figure 23. Photomicrograph of thin section of tremolite-clinozoisite skarn found near Oz Creek. Skarns typically replace marble or calcareous horizons in hornfels. Clinozoisite is zoned and twinned.

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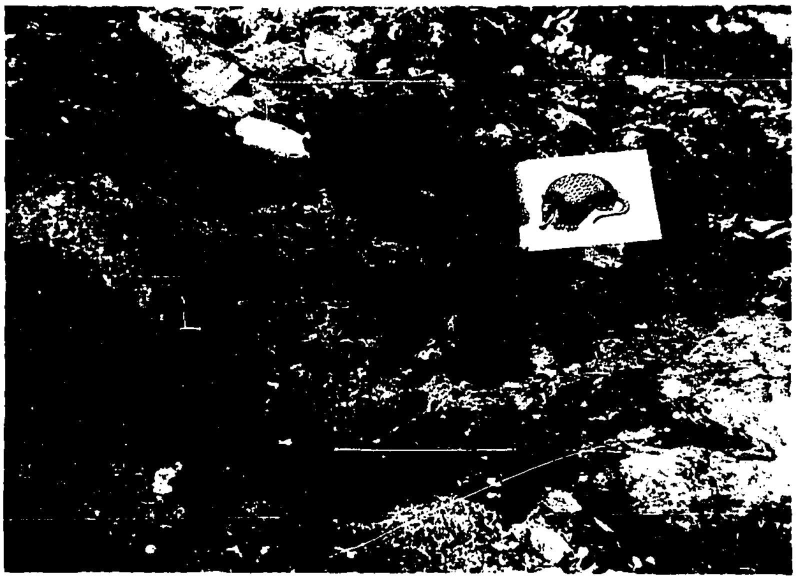

Figure 24. Photograph of outcrop of marble and pods of magnetite skarn on Pendent Peak. Pods locally contain calc-silicate minerals. Clipboard used for scale.

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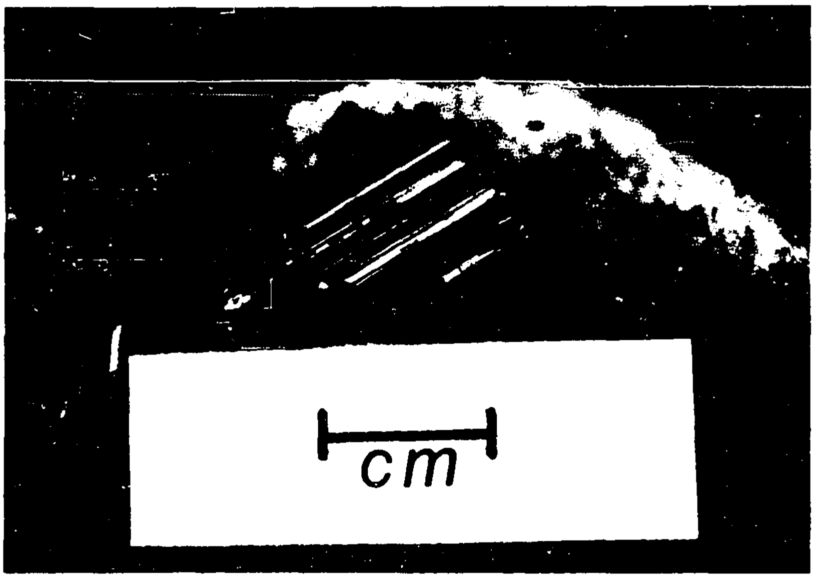

Figure 25. Photograph of hand specimen of rutile metacrysts in siderite-calcite vein found near Oz Creek. Precipitation of siderite formation is favored by lower temperatures and higher X_{CO_2} conditions.

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vein near Oz Creek is surrounded by amphibole and is associated with sphalerite and galena (?) disseminations in adjacent carbonate. A vein consisting largely of clinozoisite+tremolite crops out at one locality and has the same assemblage as the clinozoisite+tremolite skarns in this area but also contains disseminated rutile. Another type of vein which occurs in the Oz Creek vicinity contains gruneritic amphibole and trace galena and crosscuts pelitic hornfels.

Several other types of veins can be found in other portions of the contact zone. Near Pendent Peak fluorite+calcite+quartz veins are quite commonly seen crosscutting marble. Veins consisting of fibrous tremolite, smokey quartz and sheafs of prehnite crosscut calc-silicate hornfels near Arrigetch Creek. At one locality prehnite occurs with axinite. A vein consisting of quartz+calcite+beryl occurs in the contact zone near the crest of Watchtower Ridge.

Metasomatism

The conditions of metasomatism and the timing of metasomatic events were complex. However, some general inferences can be made from the compositions, textures and field relations of metasomatic rocks. Skarn formation generally postdated hornfelsing and was followed by scattered retrograding and low temperature vein formation.

Near Armadillo Peak mineral assemblages and textures of skarns and veins provide some important petrogenetic information. Clinozoisite can form from scapolite by the hydration reaction:

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scapolite + $H_2O \rightarrow$ clinozoisite + CO_2.

The formation of clinozoisite is favored by a decrease in X_{CO_2} or an increase in mole fraction H_2O and temperature. The occurrence of prehnite in these veins places some constraints on temperatures and X_{CO_2} values which were present during vein formation in this area. Referring back to Figure 19, the stability field of prehnite with respect to reaction (5) is restricted to a maximum temperature of about 405°C and a maximum X_{CO_2} value of .025. Hence this vein was probably formed at lower temperatures and X_{CO_2} conditions than were present during hornfelsing. The occurrence of axinite with prehnite in this area is an indication of local boron metasomatism.

Retrograding and veining were important metasomatic processes near Oz Creek. Pyroxene in the clinozoisite skarns and veins is partially retrograded to amphibole. This relation suggests a transition to lower temperature and/or lower X_{CO_2} conditions. The presence of sulfides near quartz veins in this area links some sulfide mineralization with the veining event(s).

The rutile-siderite vein deposit in marble near Oz Creek formed from an Fe-Ti-rich solution. Rutile can form by the decomposition of sphene according to the reaction:

sphene + $CO_2 \rightarrow$ rutile + quartz + calcite (Hunt and Kerrick, 1977).

Sphene does not occur in this vein deposit but is abundant in nearby greenschist. In a nearby occurrence of endoskarn (?) thought to be derived from greenschist, sphene is altered and replaced by salitic

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pyroxene. Metasomatism of greenschist and the breakdown of sphene could enrich passing fluids in Fe and Ti which could precipitate in veins in marble as siderite and rutile. The X_{CO_2} and pH were increased as the fluids passed through and reacted with carbonate wall rocks. Precipitation of siderite is favored by moderately reducing, lower temperature and higher X_{CO_2} conditions (Brownlow, 1979).

The combined evidence suggests a general sequence of events beginning with early hornfelsing followed by an episode of skarn formation and veining. Skarn formation was mostly at lower temperatures and lower X_{CO_2} conditions than hornfelsing. Vein formation took place at lower temperatures and was subsequent to hornfelsing and fracturing. Some veins were formed at moderately reducing and slightly higher X_{CO_2} conditions. Graphical representation of the evolving temperature and X_{CO_2} conditions is shown in Figure 26. The prograde path illustrates the effect of decarbonation and CO_2 buffering on contact-metamorphic reactions which accompanied rising temperatures (after Skippen, 1971, Greenwood, 1975 and Taylor, 1976). The retrograde path illustrates the declining temperatures and X_{CO_2} values which accompanied more open-system, metasomatic reactions.

The setting of skarn mineralization in the study area has both similarities and differences with known economic tin skarns such as the Lost River deposit of the Seward Peninsula. The Lost River granite is peraluminous, has a high initial $^{87}Sr/^{86}Sr$ ratio (.708-.721),

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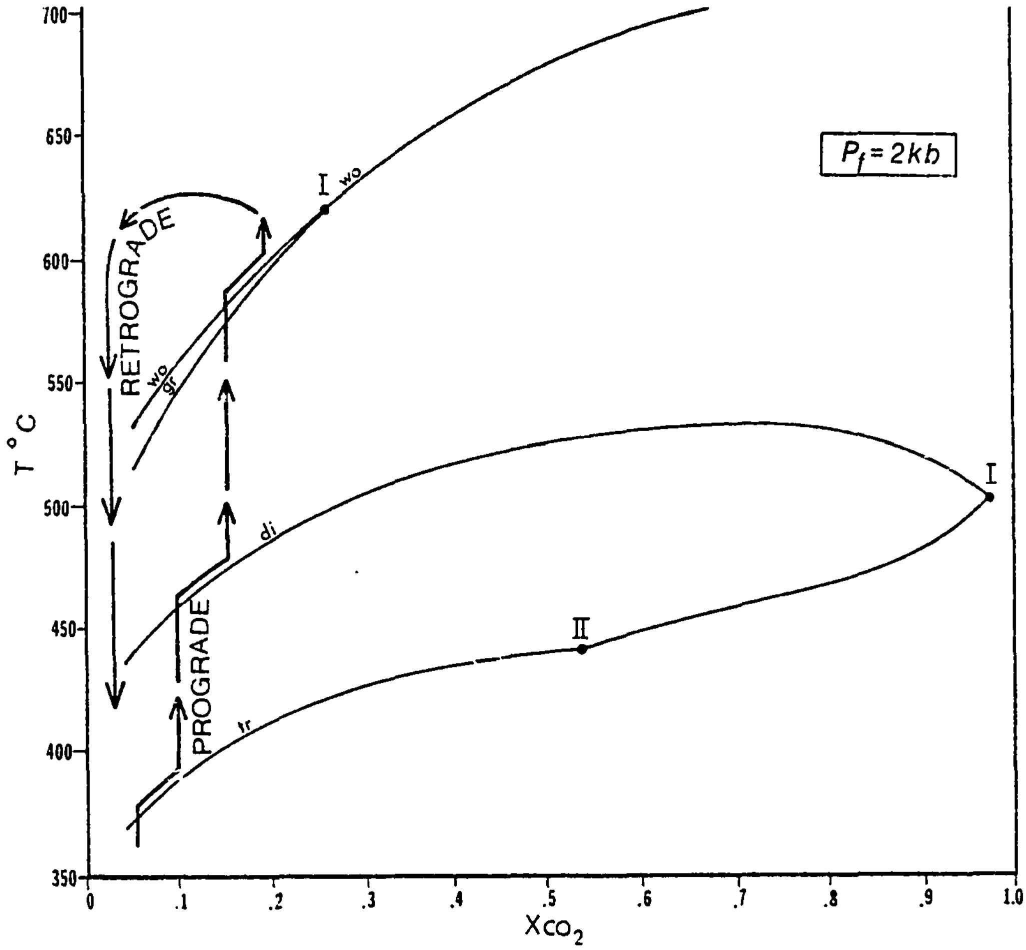

Figure 26. Isobaric T-X_{CO_2} diagram at 2 kb total fluid pressure showing general evolution of temperature and CO_2 conditions (after Skippen, 1971, Greenwood, 1975 and Taylor, 1976). Prograde path shows decarbonation and CO_2 buffering effects on contact-metamorphic reactions which accompanied rising temperatures. Retrograde path shows declining temperatures and X_{CO_2} which accompanied later metasomatic reactions. Mineral abbreviations given in Table 1; P_f = total fluid pressure.

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contains anomalous fluorine and lacks magmatic opaque phases (Dobson, 1982). These characteristics can also be applied to the Arrigetch Peaks granite orthogneiss. The intrusives in both of these areas have the characteristics of S-type or ilmenite series granitoids of the classifications of White and Chappel (1977) and Ishihara (1981) (respectively). Unlike the Lost River granite, the intrusive in the study area is well exposed, has no stockwork fracture system and lacks rhyolite dikes and greisens. Furthermore, the intrusive of the study area is Devonian (as apposed to Cretaceous) in age and is gneissic, having been subjected to at least two stages of metamorphism (Dillon and others, 1981). In both areas, granite intrudes a thick section of Paleozoic carbonates forming small amounts of garnet skarn, and in both areas endoskarn is not developed. Fluorine and beryllium are fairly common in vein mineralization of both areas, suggesting enrichment of these elements in the volatile phase during intrusion. Tin occurs in garnet in both areas, but retrograde alteration in the study area is minimal compared to the Lost River deposit where tin was apparently released from other minerals and redeposited as cassiterite (Dobson, 1982).

Anomalous Cu, Zn, Sn, W, Ag and F is found in skarns and veins near contacts of the granitic orthogneiss plutons in the Survey Pass quadrangle (Grybeck and Nelson, 1981b). Tin typically does not occur in oxide or sulfide minerals. The lack of significant economic skarn mineralization in these areas may be due to removal of cupolas by erosion, low water contents of the intrusions or emplacement

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of the plutons at moderate depths. Skarn formation is restricted at greater emplacement depths because of greatly reduced fracturing and fluid circulation. Although economic skarn mineralization is lacking around the Survey Pass granitic plutons it could be present in the contact zones of other granitic plutons on trend to the east and west.

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CONCLUSIONS

The Arrigetch Peaks pluton consists largely of granite orthogneiss in the study area. Coarse-grained augen gneiss is very common and schistose orthogneiss and dikes and sills of aplitic rock occur in the marginal pluton areas. Magma genesis involving mobilization of crustal source rocks is suggested by the high initial $^{87}Sr/^{86}Sr$ ratio for orthogneiss of the Arrigetch Peaks and Mt. Igikpak plutons (Silberman and others, 1979). U-Pb zircon age data indicate magmatic crystallization in the Devonian (Dillon and others, 1980a). K-Ar ages obtained from micas from the pluton indicate that the latest metamorphic episode ended in the Upper Cretaceous (Turner and others, 1979).

The pluton intrudes Devonian to Proterozoic (?) country rocks in the study area. Thick impure marble correlated with the Skajit Formation contains interlayered greenschist, calc-schist and quartz schist. Fossil corals from one locality in the uppermost Skajit could be from any Silurian to Permian system, but are more likely to be Silurian to Upper Devonian (Frasnian) in age (Oliver, W. A., Jr., writ. comm., 1982). Low-grade, quartz-mica schist and calc-schist occur above the Skajit in most areas except on Watchtower Ridge where some higher-grade, garnet-bearing schist is found. Garnet-mica-quartz schist commonly underlies the Skajit.

The northern contact zone of the pluton is continuous, well preserved and includes hornfels, calc-silicate marble, skarn and

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veins. Local helicitic textures found in hornfels suggest pre- or syn-intrusive deformation. Pyroxene, amphibole and garnet are very common in calc-silicate hornfels and wollastonite occurs locally. Assemblages found in mineral zones on Night Ridge indicate that the metamorphic grade in this area decreases outwards from the intrusive from the hornblende-hornfels to the albite-epidote-hornfels facies. This zonation formed largely in response to a shallow thermal gradient and changes in bulk compositions. Skarns and veins contain some anomalous Fe, Sn, Cu, Zn, Be, B and Ti and were formed at lower temperatures subsequent to most of the hornfelsing. In contrast with known economic tin skarns, tin is apparently retained in calc-silicate minerals due to the lack of extensive retrograde alteration.

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REFERENCES CITED

Albee, A. L., 1972, Metamorphism of pelitic schists: reaction relations of chloritoid and staurolite: Geol. Soc. of America Bull., v. 83, p. 3249-3268.

Atherton, M. P., 1964, The garnet isograd in pelitic rocks and its relation to metamorphic facies: Am. Mineralogist, v. 49, p. 1331-1348.

Barrow, G., 1893, On an intrusion of muscovite-biotite gneiss in the southeast Highlands of Scotland: Geol. Soc. London Quart. J., v. 49, p. 330-358.

Brosge, W. P., and Pessel, G. H., 1977, Preliminary reconnaissance geologic map of the Survey Pass quadrangles, Alaska: U.S. Geological Survey Map OF 77-27.

Brosge, W. P., and Reiser, H. N., 1971, Preliminary bedrock geologic map, Wiseman and eastern Survey Pass quadrangle, Alaska: U.S. Geological Survey OFR 71-56, scale 1:250,000.

Brownlow, A. H., 1979, Geochemistry: Prentice-Hall Inc., N.J., 498 p.

Buddington, A. F., 1959, Granite emplacement with special reference to North America: Geol. Soc. of America Bull., v. 70, p.671-747.

Dillon, J. T., and Pessel, G. H., 1979, Tectonic significance of Late Devonian and Late Proterozoic U/Pb zircon ages from metaigneous rocks, Brooks Range, Alaska: Geol. Soc. of America Abs. with Progs., v. 11, no. 3. p. 75.

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Dillon, J. T., Pessel, G. H., Chen, J. H., and Veach, N. C., 1980a, New geochronological evidence for Paleozoic magmatism and orogenesis in the southern Brooks Range, Alaska: Geology, v. 8, p. 338-343.

______________________________, 1980b, Tectonic and economic significance of Upper Devonian and late Proterozoic zircon ages from the Brooks Range, Alaska: Alaska D.G.G.S. Rept. no. 61.

Dillon, J. T., Pessel, G. H., Lueck, L. and Hamilton, W. B., 1981, Geologic map of the Wiseman A-4 Quadrangle: Alaska State D.G.G.S., AOF-124.

Dobson, D. C., 1982, Geology and alteration of the Lost River tin-tungsten-fluorine deposit, Alaska: Econ. Geol., v. 77, p. 1033-1052.

Enaudi, M. T., Meinert, L. D. and Newberry, R. J., 1981, Skarn deposits: Econ. Geol., 75th Ann. Vol., p. 317-391.

Fritts, C. E., Eakins, G. R., and Garland, R. E., 1971, Geology and geochemistry near Walker Lake, southern Survey Pass quadrangle, Arctic Alaska: Alaska D.G.G.S. Ann. Rept., p. 19-26.

Greenwood, H. J., 1975, Thermodynamically valid projections of extensive phase relationships: Am. Mineralogist, v. 60, p. 1-8.

Grybeck, D., Beikman, H. M., Brosge, W. P., Tailleur, I. L., and Mull, C. G., 1977, Geologic map of the Brooks Range, Alaska: U.S. Geol. Survey Map OF 77-166B.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.

Grybeck, D., and Nelson, S. W., 1981a, Structure of the Survey Pass quadrangle, Brooks Range, Alaska: U.S. Geol. Survey Map MF-1176-B, 8 p.

______________________________, 1981b, Mineral deposit map of the Survey Pass quadrangle, Brooks Range, Alaska: U.S. Geol. Survey Map MF-1176-F.

Hanson, G. N. and Gast, P. W., 1967, Kinetic studies in contact metamorphic zones: Geochem. et Cosmo. Acta, v. 31, p. 1119-1153.

Henning, M. W., 1982, Reconnaissance geology and stratigraphy of the Skajit Formation, Wiseman B-5 quadrangle, Alaska: Alaska State D.G.G.S. AOF-147.

Hewitt, D. A., 1975, Stability of the assemblage phlogopite-calcite-quartz: Am. Mineralogist, v. 60, p. 391-397.

Hunt, I. A. and Kerrick, D. M., 1977, The stability of sphene; experimental redetermination and geologic implications: Geochim. et Cosmo. Acta, v. 41, p. 279-288.

Miyashiro, A., 1953, Calcium-poor garnet in relation to metamorphism: Geochim. et Cosmo. Acta, v. 4, p. 179-208.

Ishihara, S., 1981, The granitoid series and mineralization: Econ. Geo., 75th Ann. Vol., p. 458-484.

Liou, J. G., 1971, Synthesis and stability relations of prehnite $Ca_2Al_2Si_3O_{10}(OH)_2$: Am. Mineralogist, v. 56, p. 507-531.

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Mull, C. G., 1977, Apparent south-vergent folding and possible nappes in the Schwatka Mountains, in Blean, K. M., ed., The United States Geological Survey in Alaska-Accomplishments during 1976: U.S. Geol. Survey Circ. 751-B, p. B29-B30.

Mull, C. G., and Tailleur, I.L., 1977, Sadlerochit (?) Group in the Schwatka Mountains, southcentral Brooks Range, in Blean, K. M., ed., The United States Geological Survey in Alaska-Accomplishments during 1977: U.S. Geol. Survey Circ. 751-B, p. B27-B29.

Nelson, S. W., and Grybeck, D., 1978, The Arrigetch Peaks and Mt. Igikpak plutons, Survey Pass quadrangle, Alaska, in Johnson, K. M., ed., The United States Geological Survey in Alaska-Accomplishments during 1978: U.S. Geol. Survey Circ. 804-B, p. B16-B18.

____________________, 1979, Tectonic significance of metamorphic grade distribution, Survey Pass Quadrangle, Alaska, in Johnson, K. M., and Williams, J. R., eds., The United States Geological Survey in Alaska-Accomplishments during 1978: U.S. Geol. Survey Circ. 804-B, p. B16-B18.

____________________, 1980, Geologic map of the Survey Pass quadrangle, Brooks Range, Alaska: U.S. Geol. Survey Map MF 1176-A.

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Nelson, S. W., Grybeck, D., Silberman, M. L., and Brookins, D. G., 1978, Cataclastic granitic rocks in the central Brooks Range, Alaska: Progs. with Abs., Cordilleran Section of the Geol. Soc. of America, 75th Annual Meeting, April 9-11, 1979, San Jose State University, San Jose, California, p. 119.

Newman, G. W., Mull, C. G. and Watkins, N. D., 1977, Northern Alaska Paleomagnetism, plate rotation and tectonics: Alaska Geological Society Symposium, Anchorage, Program and Abstracts, P. 16-19.

Nilsen, T. H. and Moore, T. E., 1982, Sedimentology and Stratigraphy of the Kanayut Conglomerate, central and western Brooks Range, Alaska-Report of the 1981 field season: U.S. Geol. Survey OF 82-674.

Patton, W.W., Jr., Tailleur, I. L., Brosge, W. P. and Lanphere, M. A., 1977, Preliminary report on the ophiolites of northern and western Alaska _in_ Coleman, R. G., and Irwin, W. P., eds., North American ophiolites: Oregon Department of Geology and Mineral Industries Bulletin 95, p. 51-58.

Roeder, D. and Mull, C. G., 1978, Tectonics of Brooks Range ophiolites, Alaska: A.A.P.G. Bull., v. 62, p. 1696-1713.

Schrader, F. C., 1904, A reconnaissance in northern Alaska across the Rocky Mountains, along Koyukuk, John, Anaktuvuk and Colville Rivers and the Arctic coast to Cape Lisburne, in 1901, _with notes by_ W. J. Peters: U.S. Geol. Survey Prof. Paper 20, 139 p.

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Shand, S. J., 1927, Eruptive Rocks: Wiley, New York, 4th ed.

Silberman, M. L., Brookins, D. G., Nelson, S. W., and Grybeck, D., 1979, Rb-Sr and K-Ar data bearing on the age, origin and time of metamorphism of the Arrigetch Peaks and Mt. Igikpak plutons, Survey Pass quadrangle, Alaska, in Johnson, K. M., ed., The United States Geological Survey in Alaska-Accomplishments during 1978: U.S. Geol. Survey Circ. 804-B, p. B18-B19.

Skippen, G. B., 1971, Experimental data for reactions in siliceous marbles: J. Geol., v. 79, p. 457-481.

Slaughter, J. Kerrick, D. M. and Wall, V. J., 1975, Experimental and thermodynamic study of equilibria in the system CaO-MgO-SiO_2-H_2O-CO_2: Am. Jour. of Science, v. 275, p. 143-162.

Smith, P. S., 1913, The Noatak-Kobuk region, Alaska: U.S. Geol. Survey Bull., 536, 160 p.

Smith, P. S., and Mertie, J. B., 1930, Geology and mineral resources of Alaska: U.S. Geol. Survey Bull., 815, 351 p.

Spry, A., 1969, Metamorphic textures: Permagon Press, Ltd., N.Y., 350 p.

Streckheisen, A., 1967, To each plutonic rock its proper name: Earth Sci. Rev., v. 12, p. 1-33.

Tailleur, I. L., 1973, Probable rift origin of Canada Basin, Arctic Ocean, in Pitcher, M. G., ed., Arctic Geology: Am. Assoc. of Petroleum Geologists Memoir 19, p. 526-535.

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Taylor, B. E., 1977, Stable isotope studies of metasomatic Ca-Fe-Al-Si skarns and associated metamorphic and igneous rocks, Osgood Mountains, Nevada: Contrib. Mineral. Petrol., v. 63, p. 1-49.

Turner, D. L., 1973, Geochronology of southwestern Brooks Range metamorphic rocks: Alaska D.G.G.S. Ann. Rept., p. 27-30.

Turner, D. L., Forbes, R. B., and Dillon, J. T., 1979, K-Ar geochronology of the southwestern Brooks Range, Alaska: Canadian J. Earth Science. v. 16, p. 1789-1804.

Turner, D. L., Forbes, R. B., and Mayfield, C. F., 1978, K-Ar geochronology of the Survey Pass, Ambler River and eastern Baird Mountains quadrangles, southwest Brooks Range, Alaska: U.S. Geol. Survey OFR 78-254, 41 p.

Turner, F. J., 1981, Metamorphic petrology: McGraw-Hill Book Co., N.Y., 2nd ed., 524 p.

White, A. J. R., and Chappell, B. W., 1977, Ultrametmorphism and granitoid genesis: Tectonophysics, v. 43, p. 7-22.

Winkler, H.G.F., 1976, Petrogenesis of metamorphic rocks: Springer-Verlag, N. Y., 334 p.

Yoder, H. S. and Eugster, H. P., 1954, Phlogopit synthesis and stability range: Geochim. et Cosmo. Acta, v. 6, p. 157-185.

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Yorath, C. J. and Norris, D. K., 1975, The tectonic development of the southern Beaufort Sea and its relationship to the origin of the Arctic Ocean basin, in Yorath, C. J., Parker, E. R. and Glass, D. J., eds., Canada's continental margins and off-shore petroleum exploration: Can. Soc. of Petroleum Geologists Memoir 4, p. 589-611.

Zen, E., 1960, Metamorphism of lower Paleozoic rocks in the vicinity of the Taconic Range in west-central Vermont: Am. Mineralogist, v. 435, p. 129-175.

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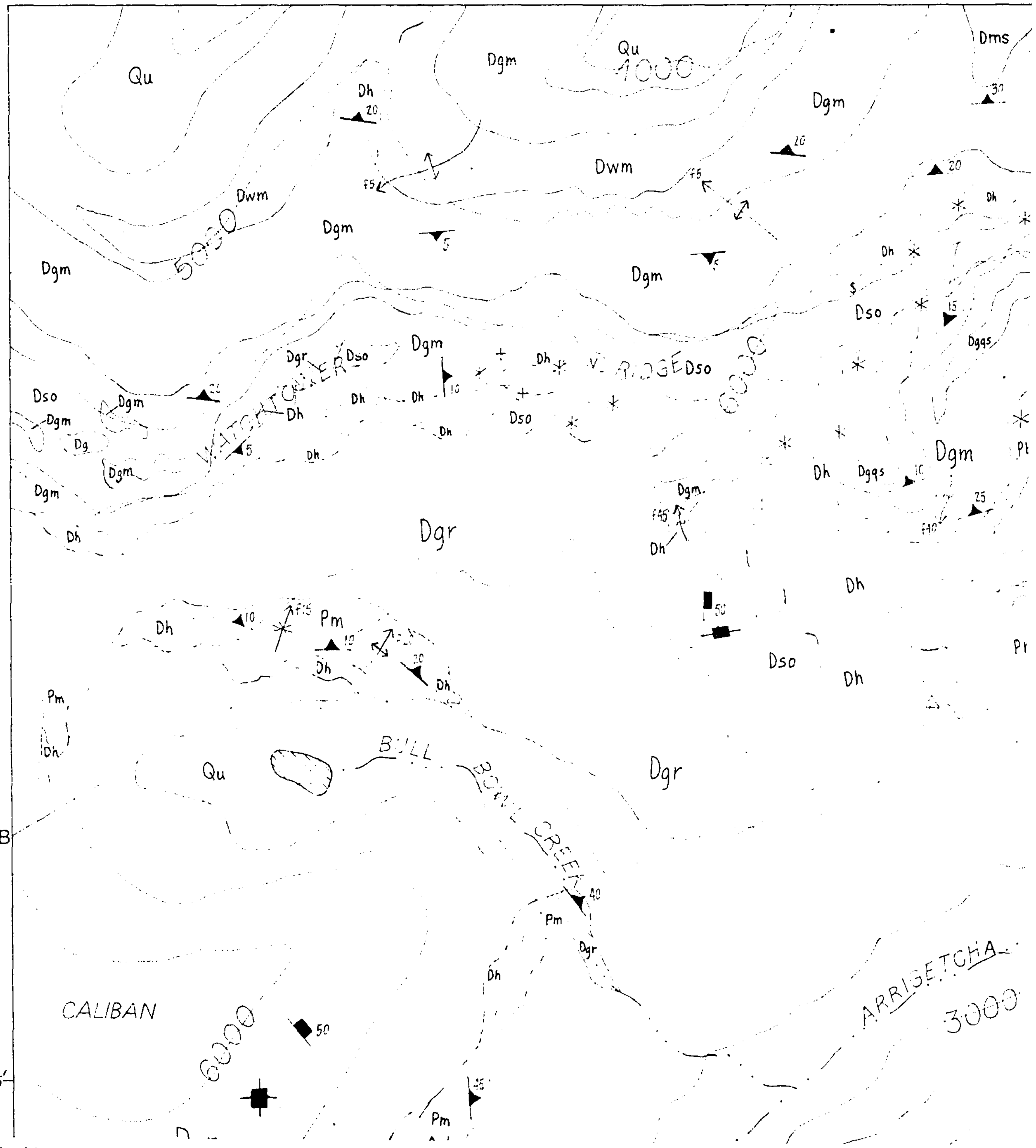

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E NORTHERN CONTACT AREA

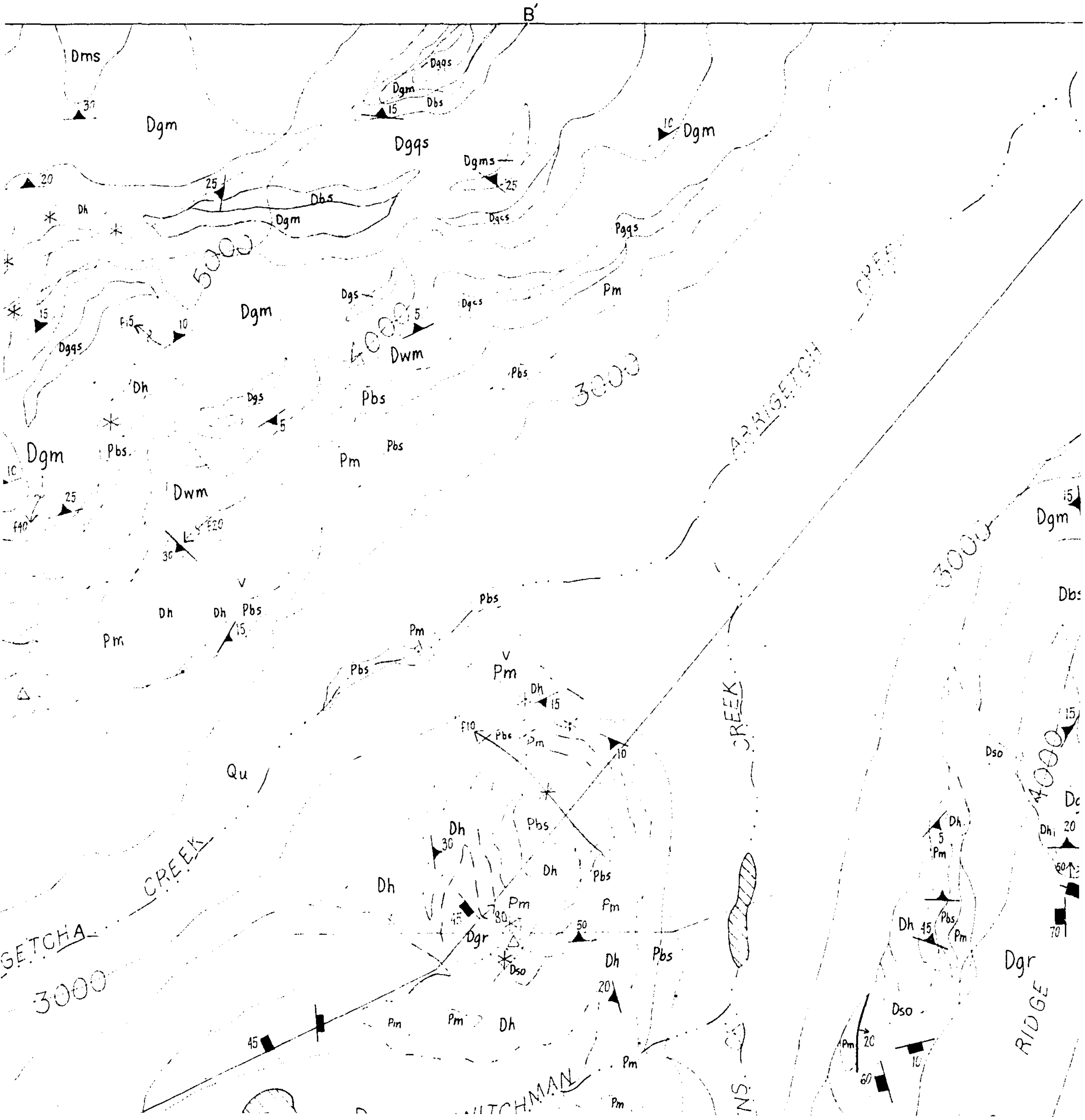

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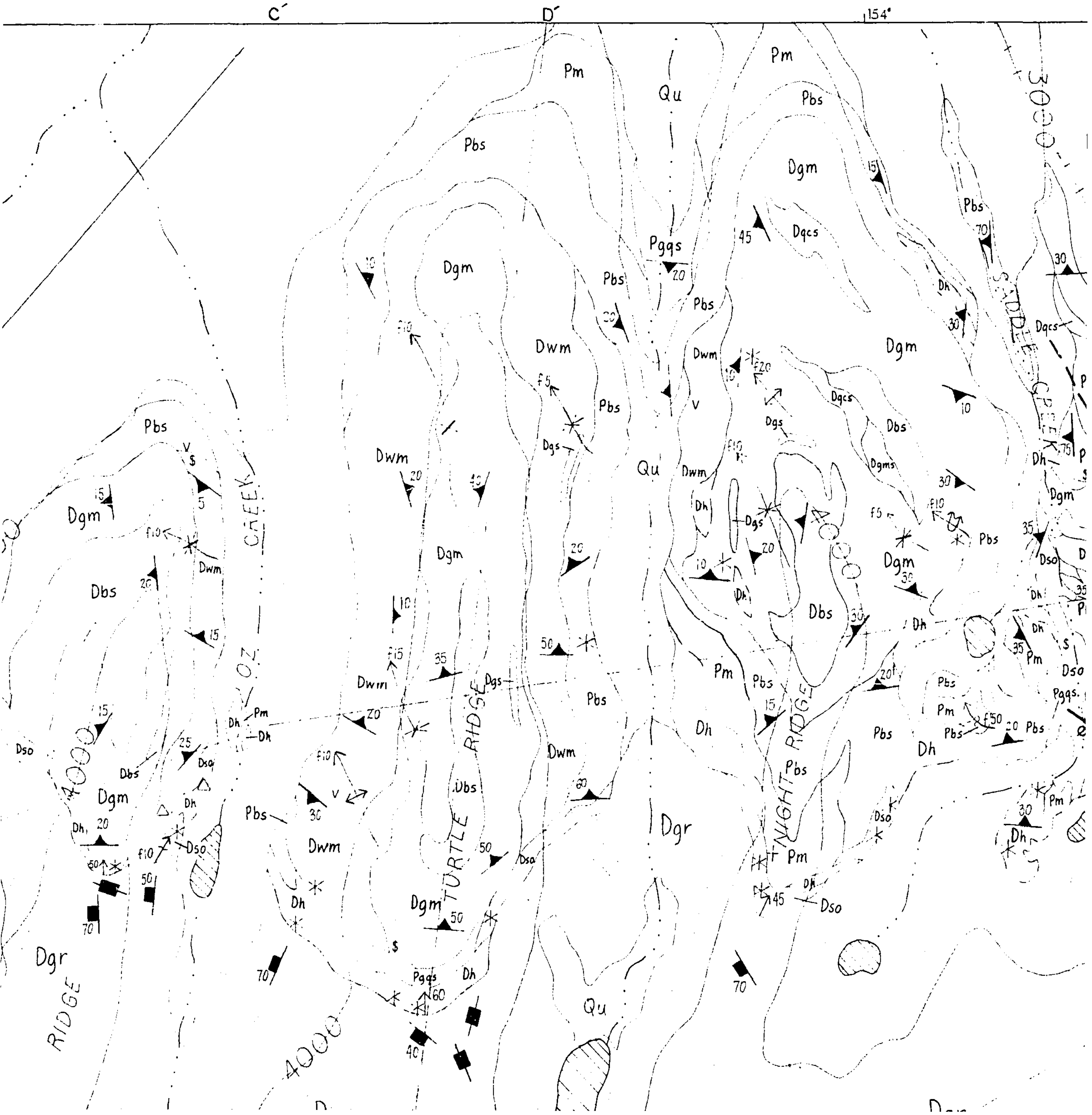
PLATE 1

EA OF ARRIGETCH PEAKS PLU



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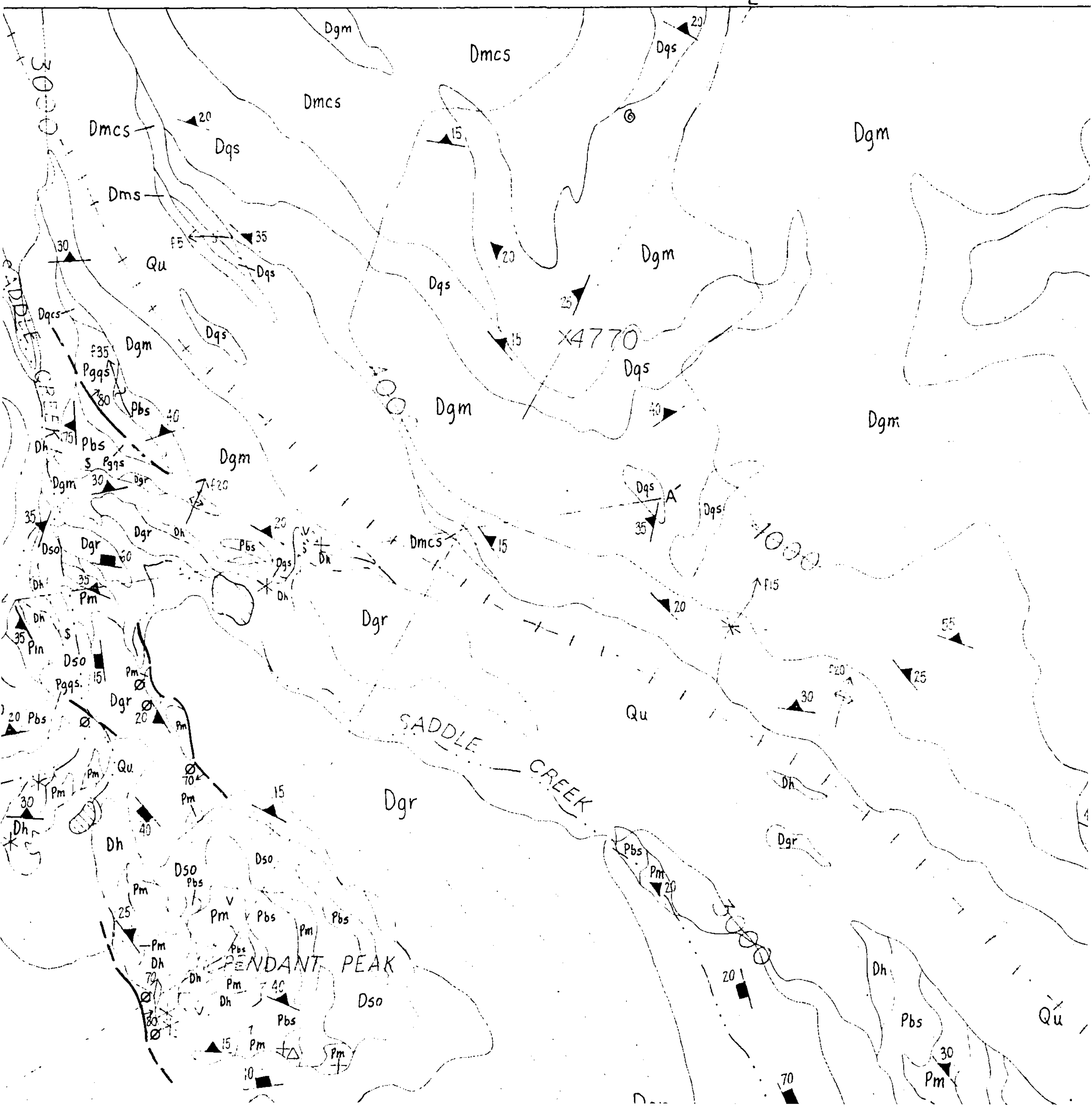
LUTON, BROOKS RANGE, ALAS



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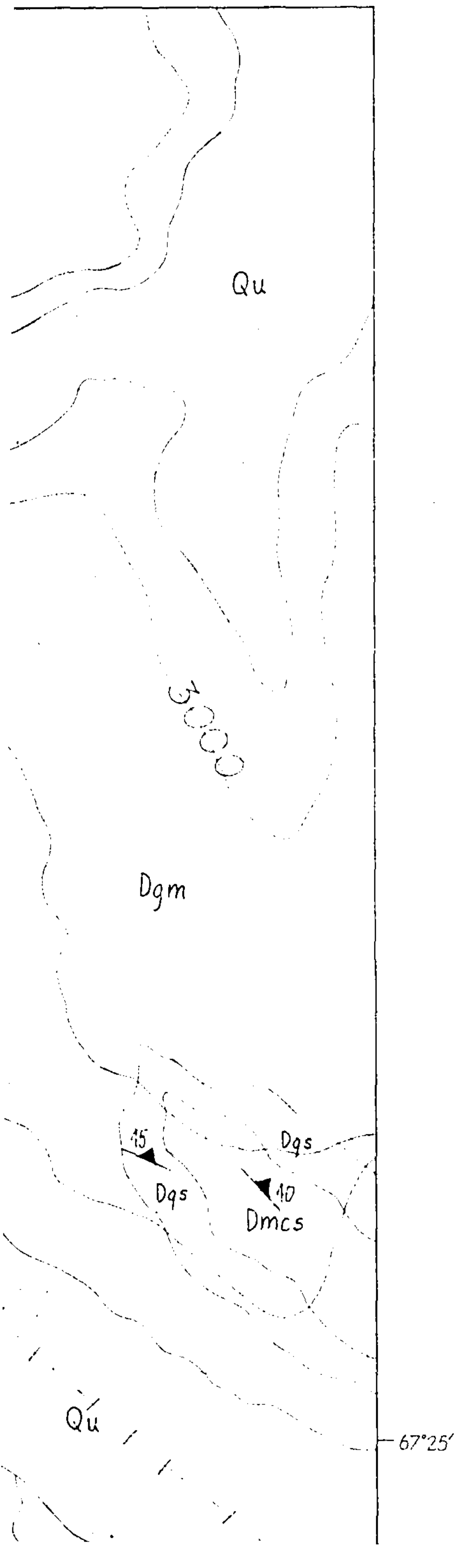

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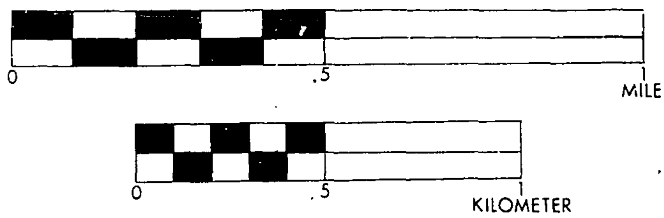

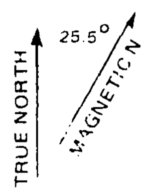

APPROXIMATE MEAN DECLINATION, 1979

ALASKA

Study area location

Symb

30 Foliation strike and dip.

60 Joint set strike and dip

* Felsic dikes and sills.

△ Skarn.

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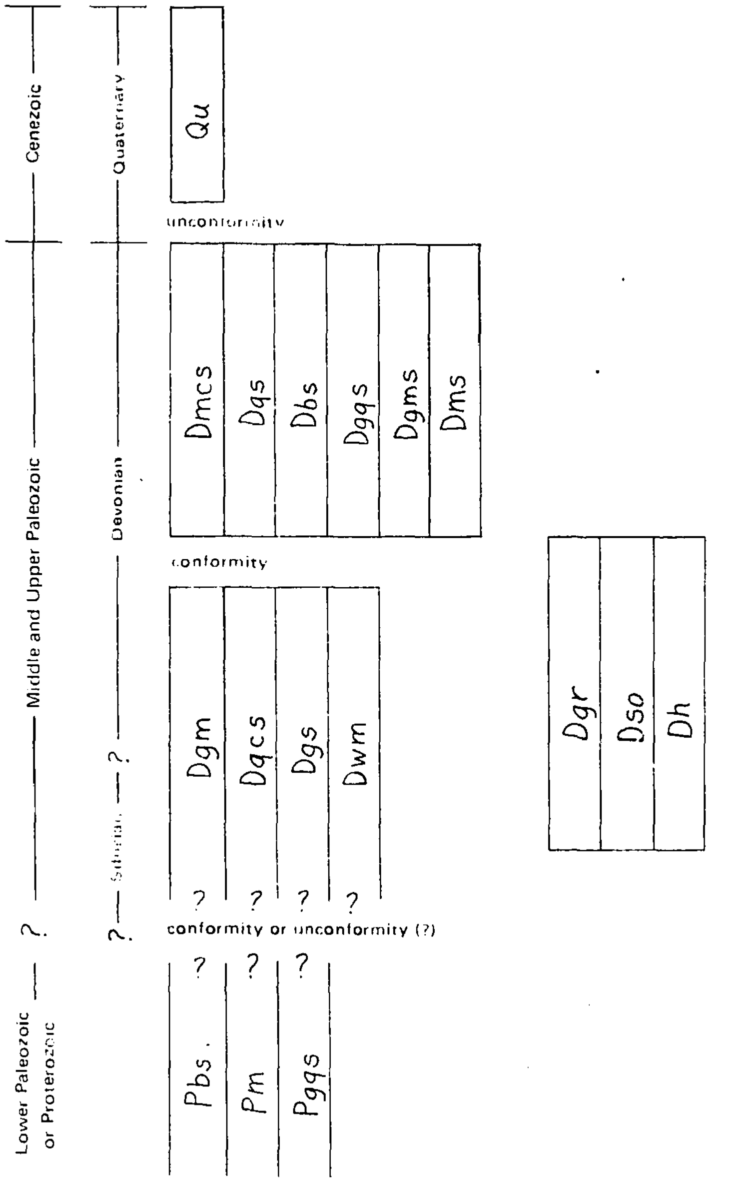
CORRELATION OF MAP UNITS



Symbols

...s and sills.

Lithologic contact, dashed where gradational or approximate.

Fault, dashed where approximated, dip shown.

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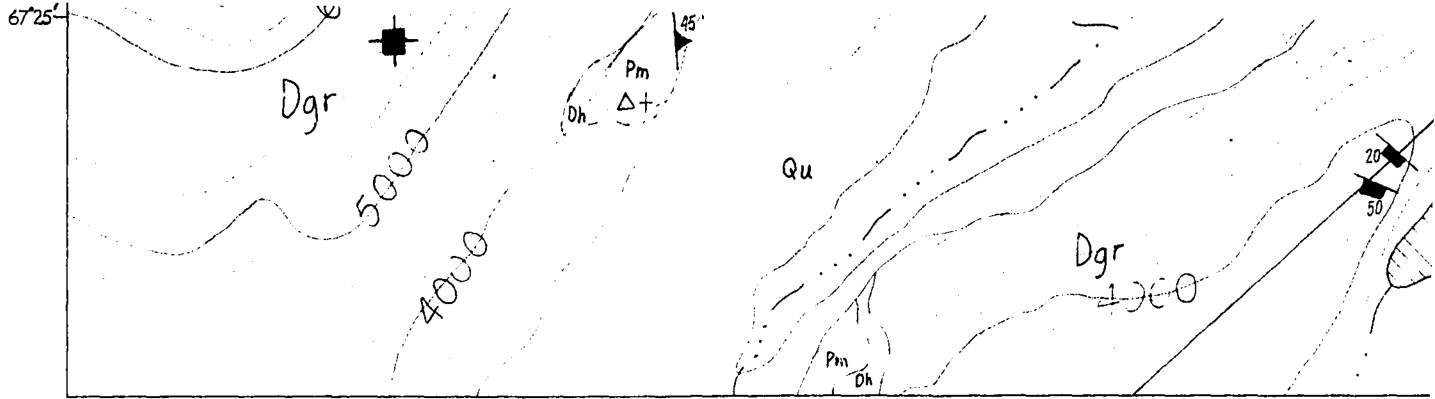
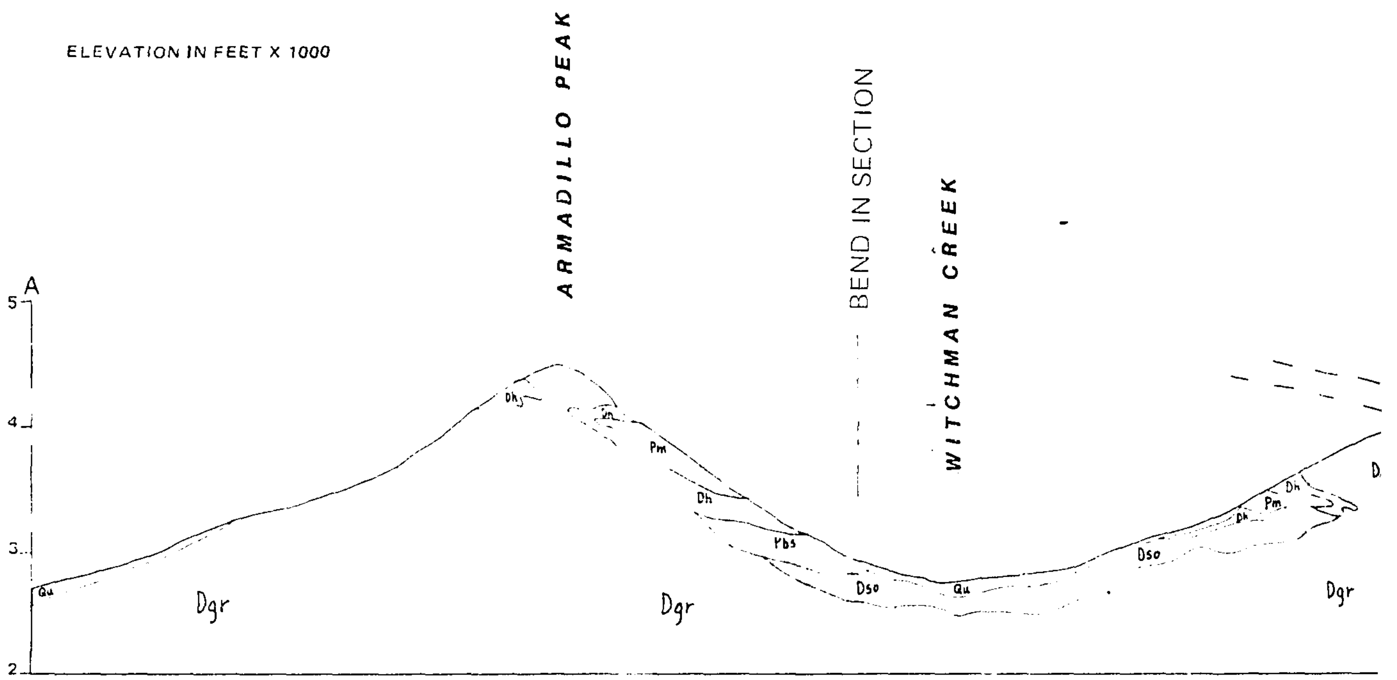
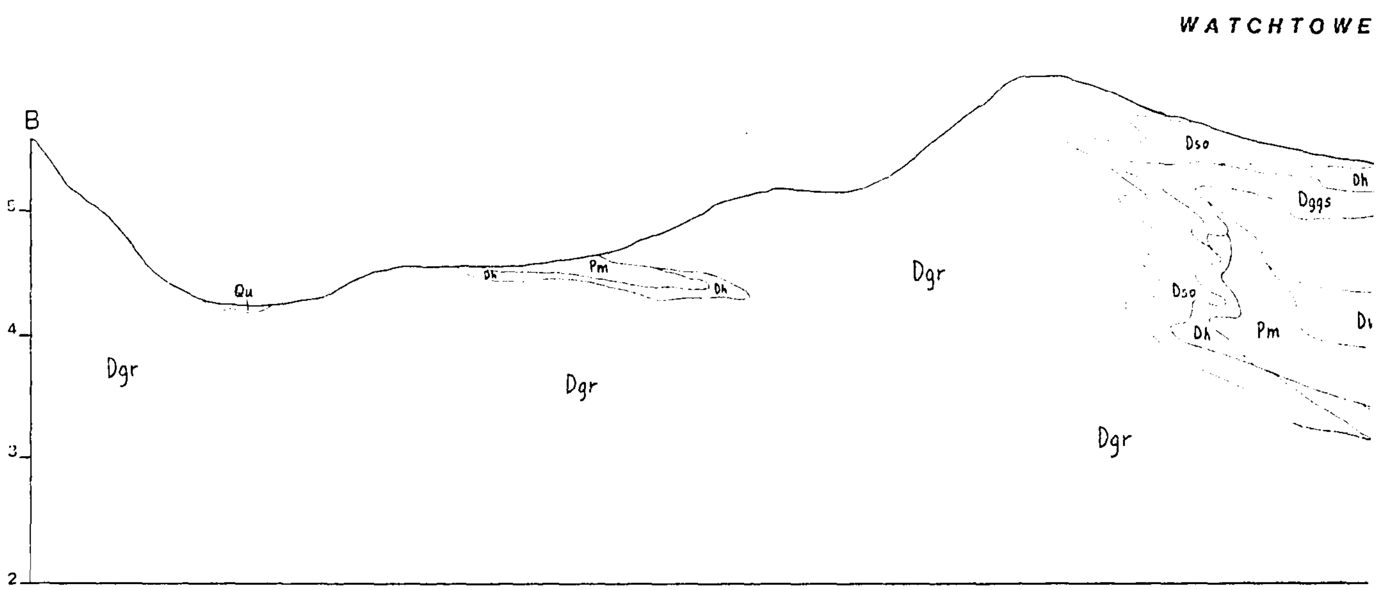


Base from U. S. Geological Survey Survey Pass B-2 and B-3 quadrangles.
All place names informal except Arrigetch Creek.

Structure Sections

ELEVATION IN FEET X 1000





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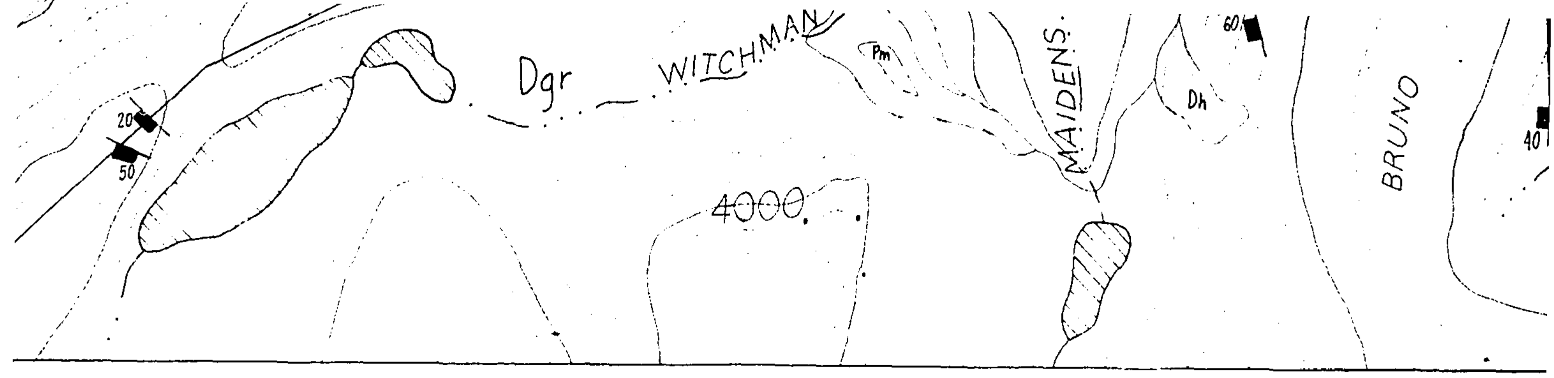

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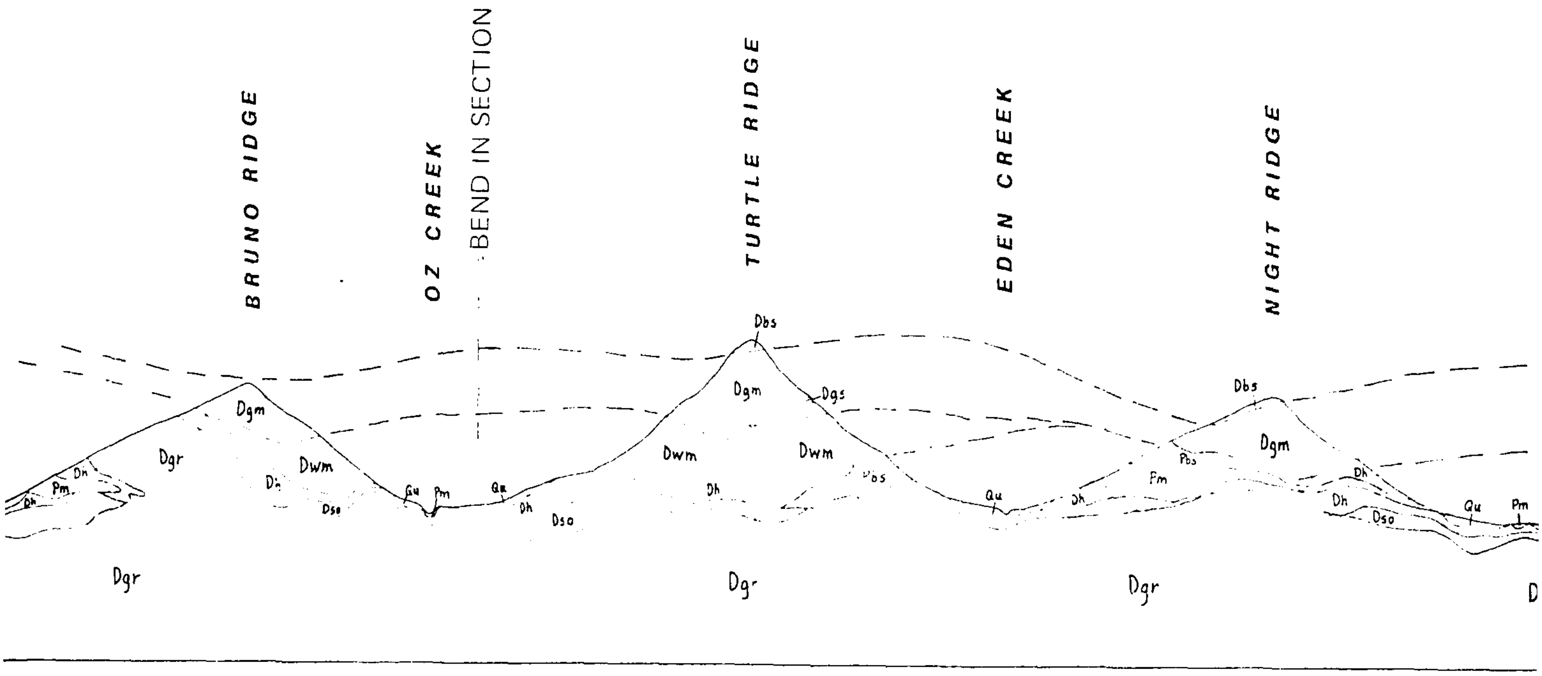

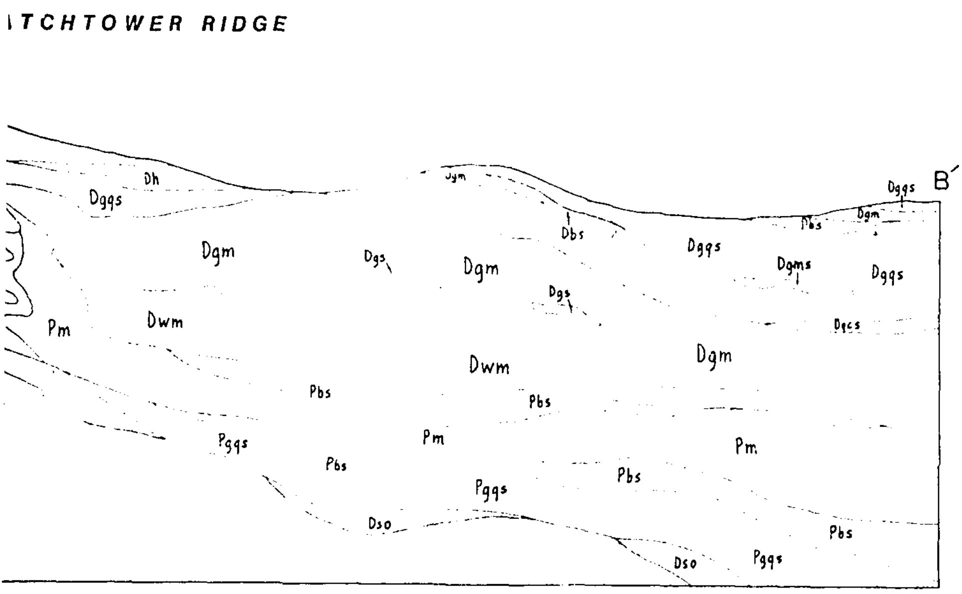

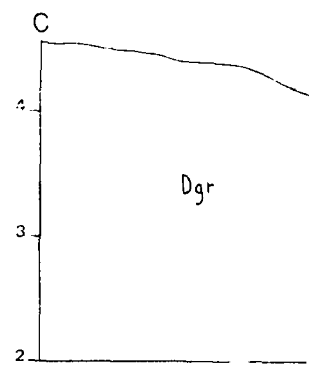

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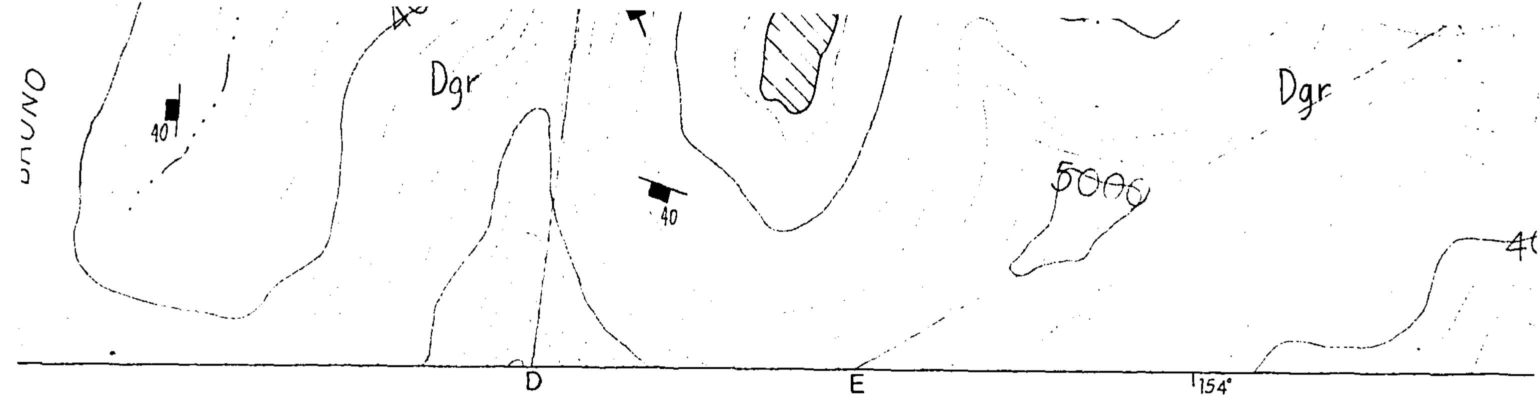
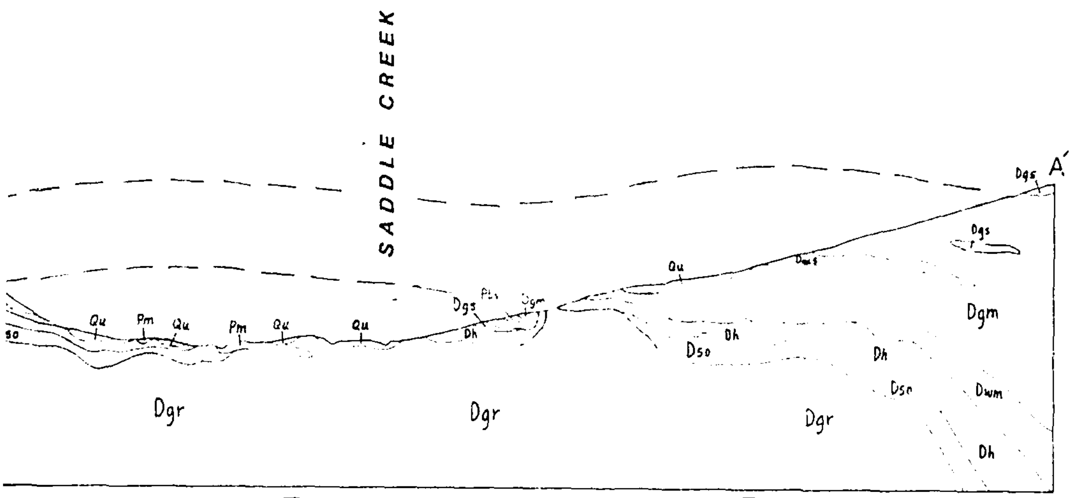
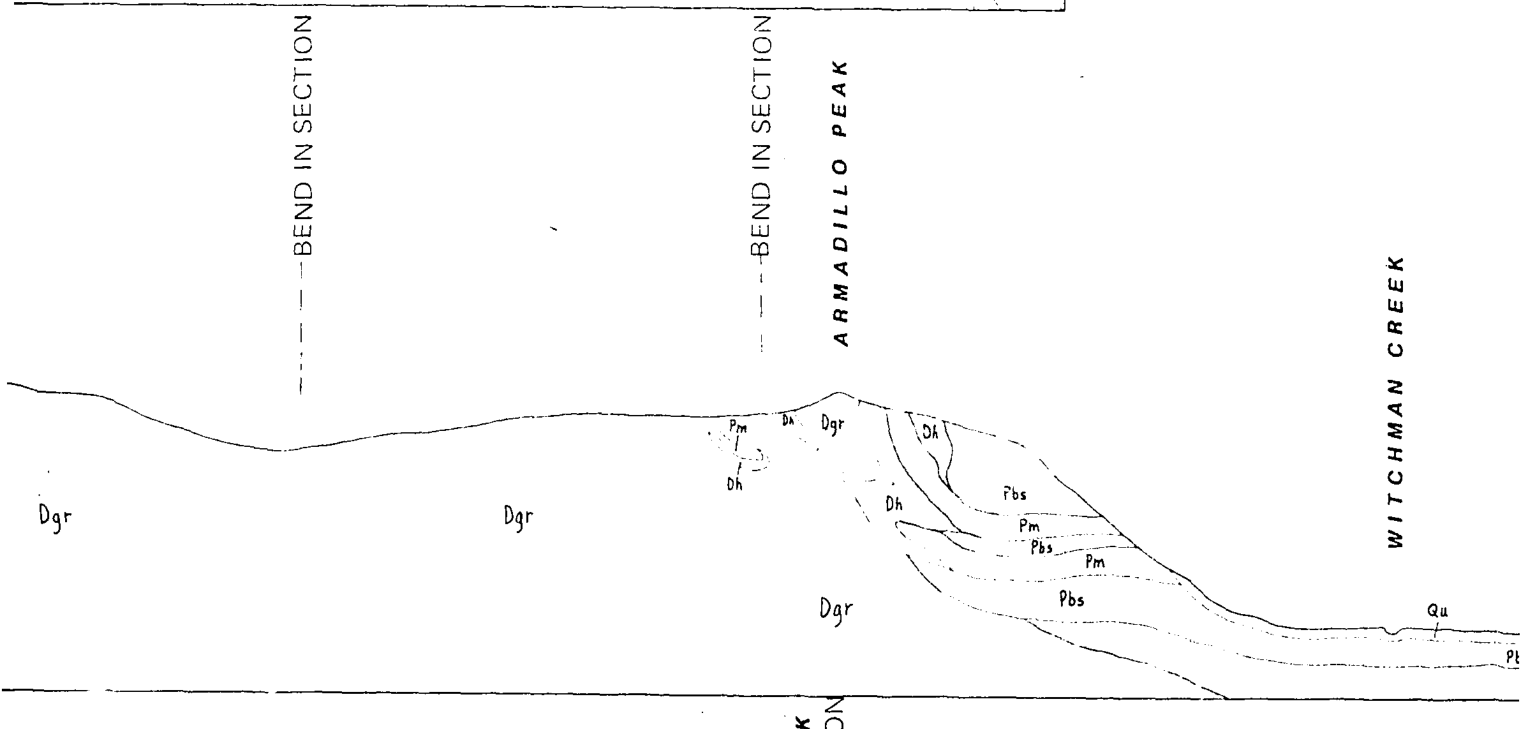


By David D. Adams

1983





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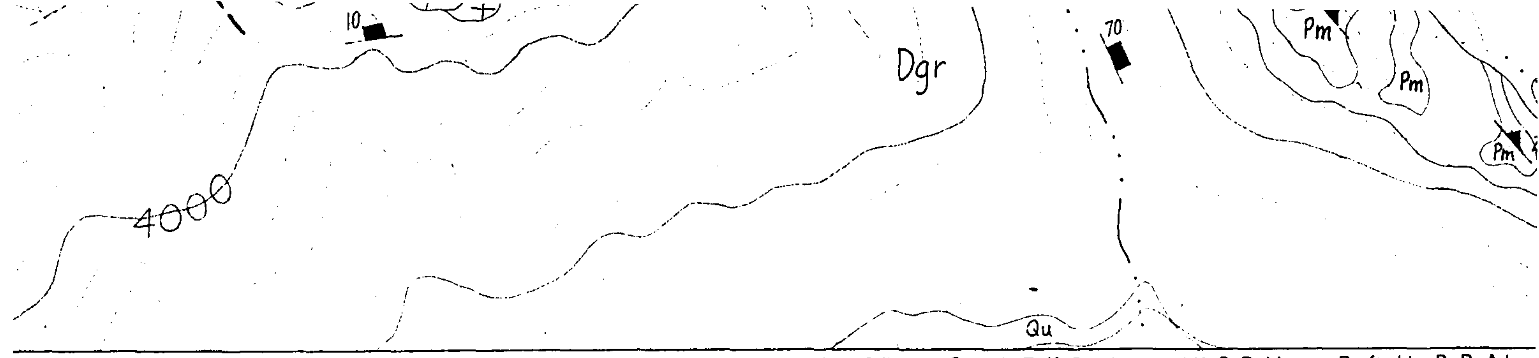
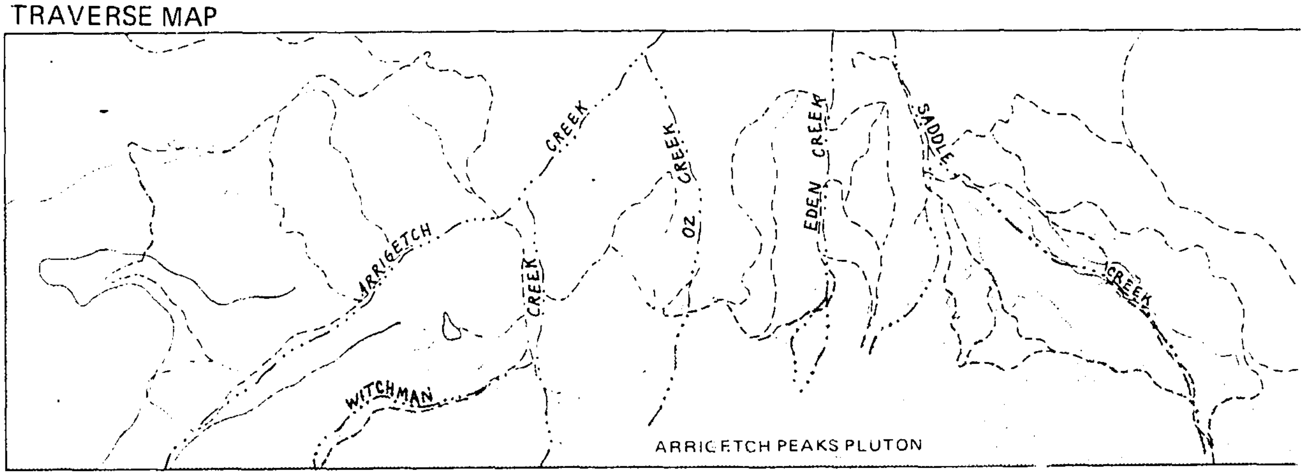
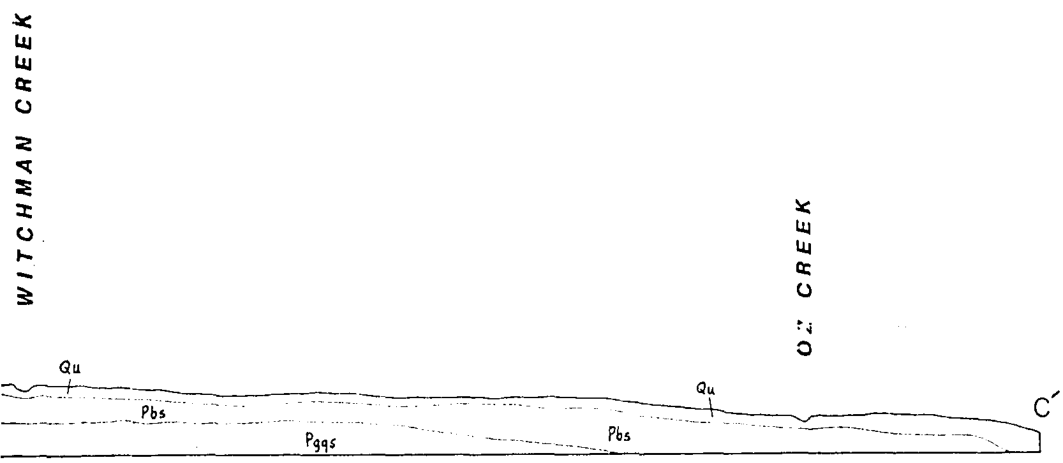


Reviewed by J. T. Dillon, C. G. Mull, T. K. Bundtzen and M. S. Robinson. Drafted by D. D. Adam

TRAVERSE MAP





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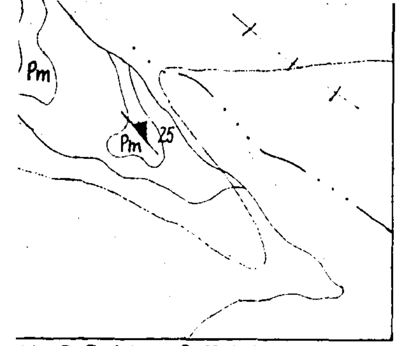


d by D. D. Adams, G. M. Laird and P. Adler.

60 Joint set strike and dip.

Vertical joint set strike.

Horizontal joint set.

70 Intrusive contact dip.

v Vein deposit.

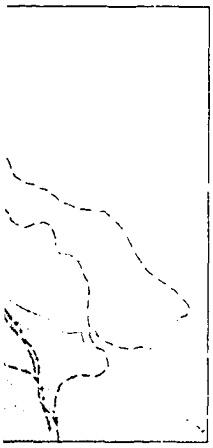
\+ Magnetite mineralization

ø Fluorite mineralization.

$ Gossan and/or sulfide mir

Fossil locality.

Map



Qu Undifferentiated alluvial, colluvial and glacial deposits. Includes morraines of the Itk

Dgr White to gray, fine- to very coarse-grained, granite to quartz monzonite orthogneiss (occur in marginal areas. Relict schleiren and large- or small-scale banding are comm

Alkali-feldspar is perthitic; plagioclase ranges from albite to oligoclase in compositic augen. Quartz and feldspar have local granulated textures in thin section. Recryst cassiterite and garnet; secondary minerals include biotite, white mica, chlorite, garr

Dso Brown to gray, fine- to medium-grained, schistose orthogneiss of the Arrigetch Peaks Dgr. Contacts with unit unit Dgr are gradational.

Dh Green, fine- to coarse-grained, calc-silicate and calcareous hornfels and lesser calc-sili

Diopsidic pyroxene, garnet (grossularite ?) and amphibole (tremolite-actinolite) are and alkali-feldspar occur as minor or accessory minerals. Typical retrograde miner are rare and in one locality consists of biotite+garnet (almandine ?)+plagioclase+m

Calc-silicate skarn typically occurs as discontinuous zones in hornfels or marble. S garnet and fluorite+magnetite (ribbon skarn). Vein minerals include prehnite, axi Sulfide minerals occur rarely in skarns or veins and include chalcopyrite, pyrite, sp

Dmcs Green to orange, medium- to coarse-grained, quartz-chlorite-white mica calc-schist.

Unit Dmcs and units Dqs, Dbs, Dgqs, Dgms and Dms (below) are thought to correla north in the Survey Pass quadrangle or may correlate in part with the Hunt Fork Sh

Dqs Green to gray, medium- to coarse-grained, white mica-chlorite-quartz schist.

Dbs Brown to gray, fine- to coarse-grained, chlorite-white mica-biotite quartz schist wit

Dgqs Green to buff, fine- to coarse-grained, garnet (almandine ?)-biotite-white mica-chlor

Dgms Green, fine- to coarse-grained, porphyroblastic, garnet (almandine)-biotite-chlorite

Dms Gray to green, fine- to coarse-grained, graphitic, quartz-white mica-chlorite schist.

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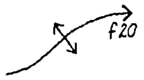
posit.

te mineralization.

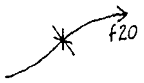
: mineralization.

nd/or sulfide mineralization.

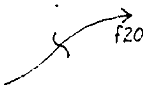
locality.



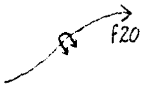
Anticline fold axis approximate trend and plunge.



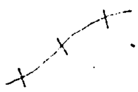
Syncline fold axis approximate trend and plunge.



Trend and plunge of small-scale similar folds.



Overturned anticline fold axis trend and plunge.



Approximate location of garnet isograd.

Map Units

orraines of the Itkillik Glaciation.

inite orthogneiss of the Arrigetch Peaks pluton. Dikes and sills of aplitic rock and schistose orthogneiss (unit Dso) ianding are common. Contacts of the pluton with country rocks are largely discordant but are locally concordant.

lase in composition. Recrystallized biotite and white mica define the foliation(s) which typically surrounds perthite section. Recrystallized quartz forms lenses. Accessory minerals include zircon, apatite, ilmenite, allanite, fluorite, iica, chlorite, garnet, sphene, epidote, calcite, hematite and kaolinite.

ie Arrigetch Peaks pluton. Contains abundant biotite and white mica but otherwise has mineralogy similar to unit

and lesser calc-silicate marble. Includes skarn and vein deposits.

lite-actinolite) are most common minerals. Wollastonite, idocrase, phlogopite, biotite, plagioclase, calcite, quartz retrograde minerals include amphibole, chlorite, epidote, clinozoisite, zoisite and white mica . Pelitic hornfels ?)+plagioclase+magnetite with retrograde chlorite+siderite.

ofels or marble. Skarn mineralogies include clinozoisite+tremolite, garnet+pyroxene, scapolite+garnet, magnetite+ ude prehnite, axinite, tremolite, clinozoisite, calcite, siderite, quartz, beryll, fluorite, rutile, chlorite and grunerite. opyrite, pyrite, sphalerite and galena.

mica calc-schist.

hought to correlate with mid- to Upper Devonian metasediments which overlie the Skajit Formation further the Hunt Fork Shale Formation.

irtz schist.

quartz schist with accessory epidote and calcite.

e-white mica-chlorite quartz schist.

:)-biotite-chlorite schist with accessory quartz, calcite, white mica and opaque minerals.

ca-chlorite schist. Contains accessory calcite and includes chloritoid-bearing schist in northwest map area.

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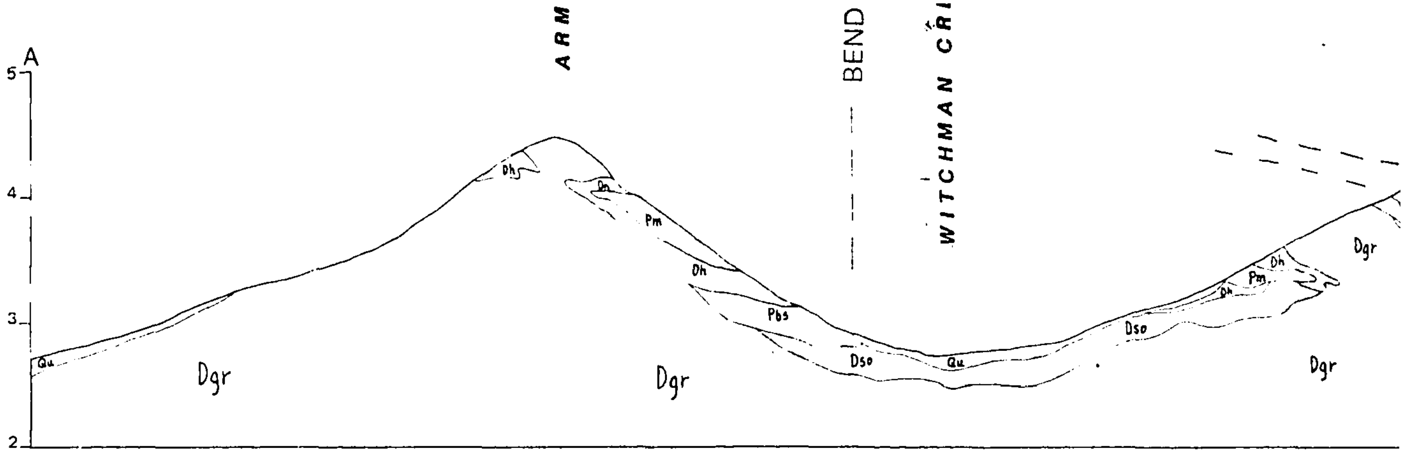

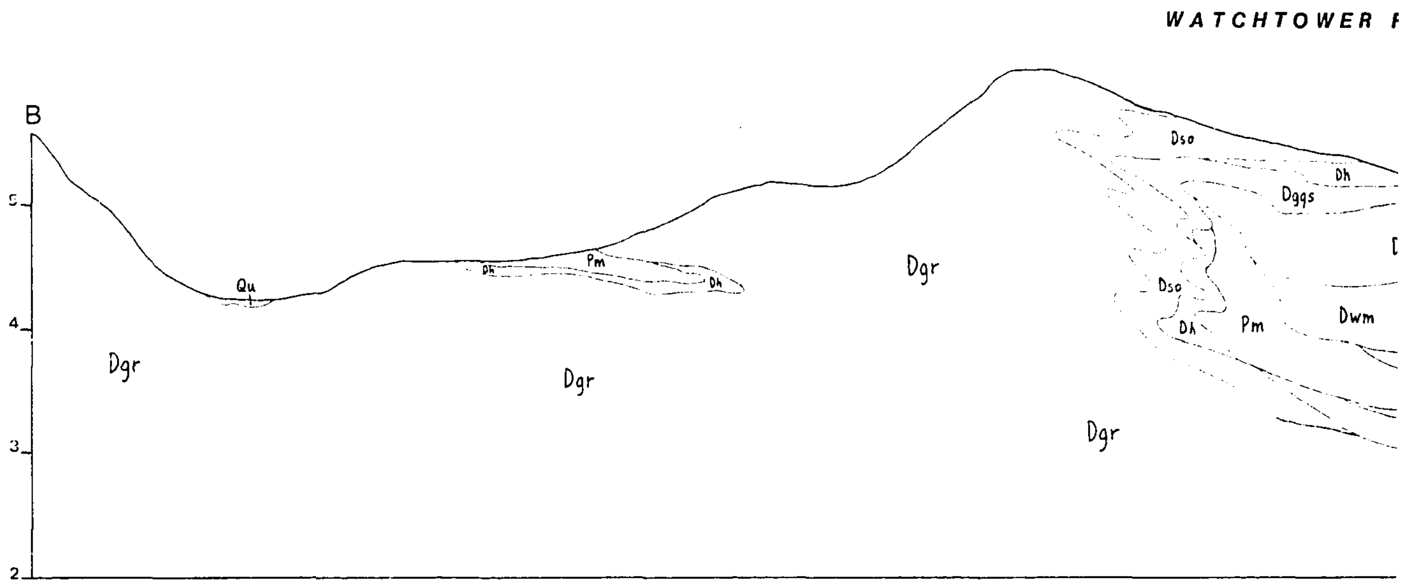

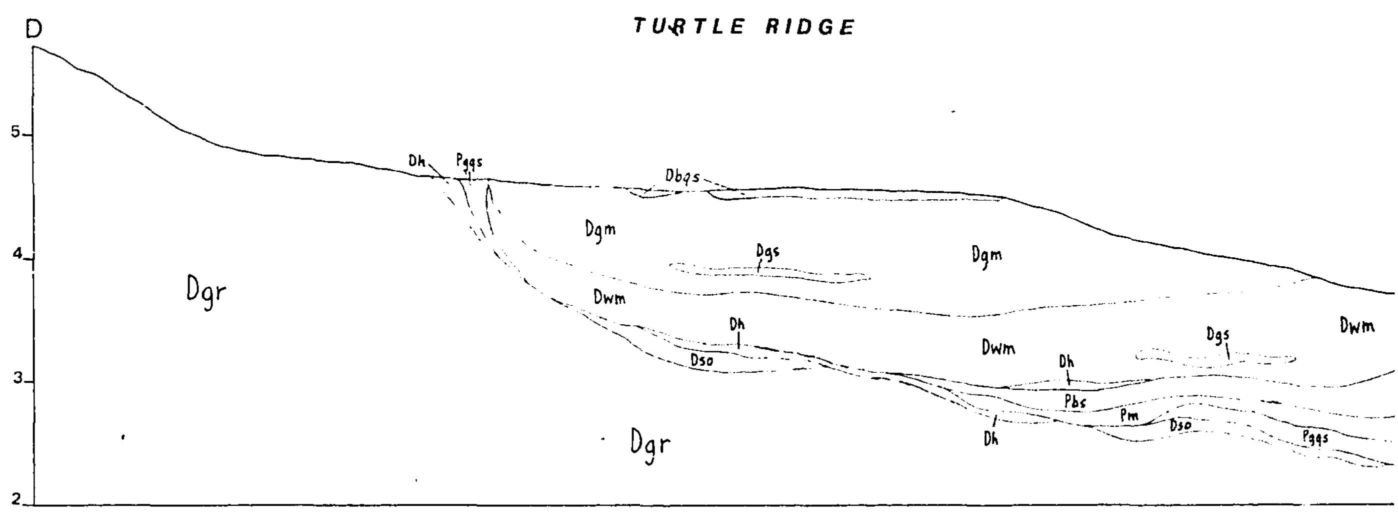

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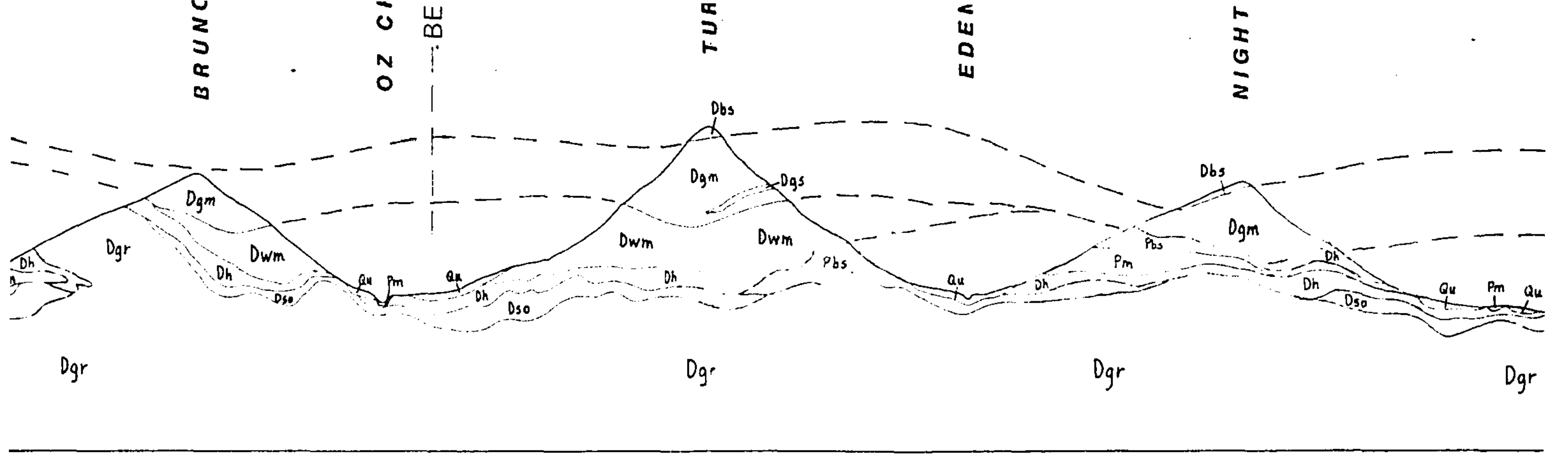
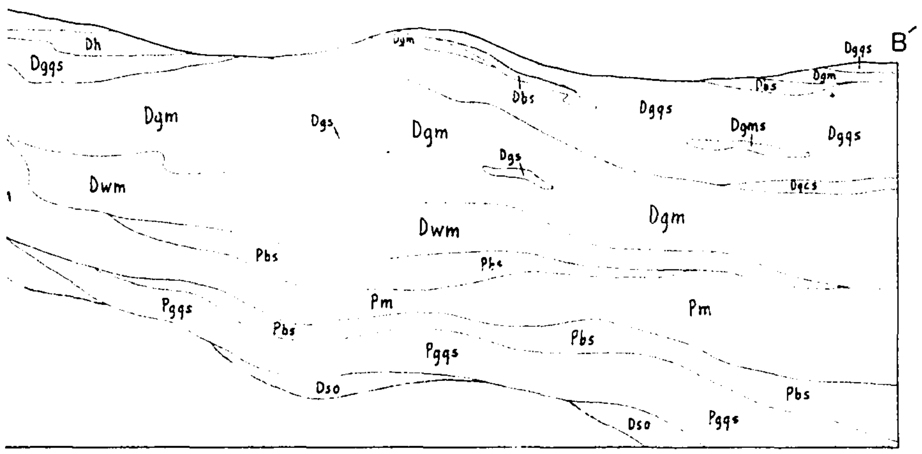
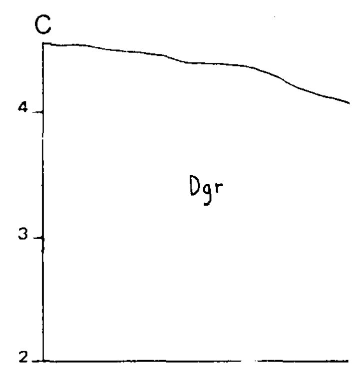
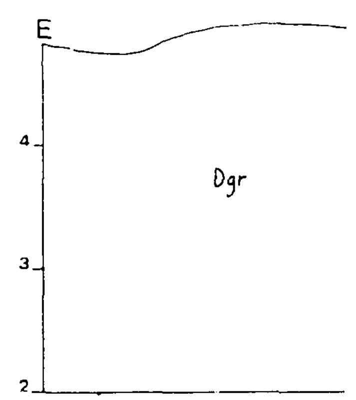
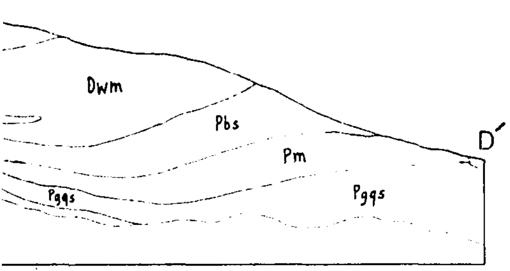


ITOWER RIDGE









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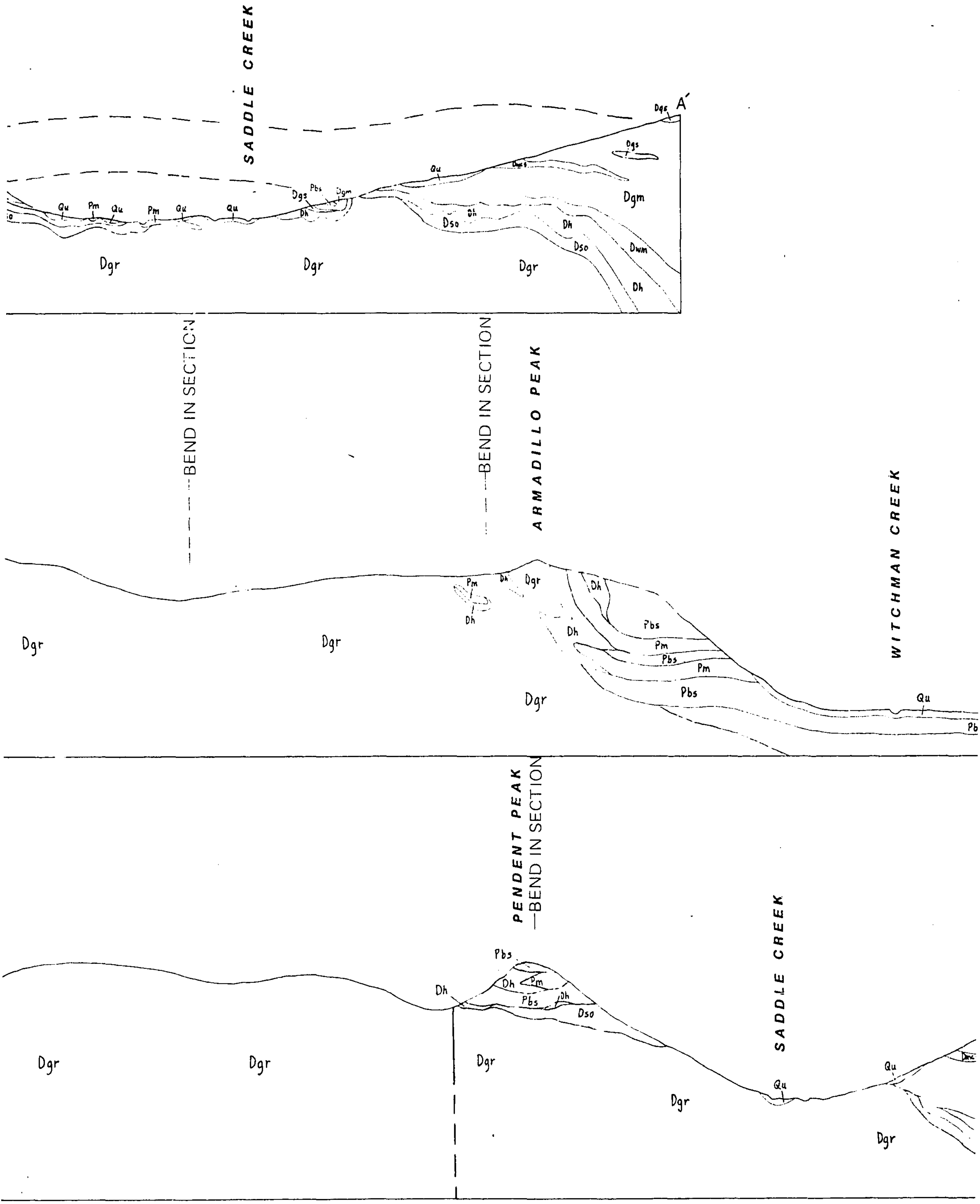

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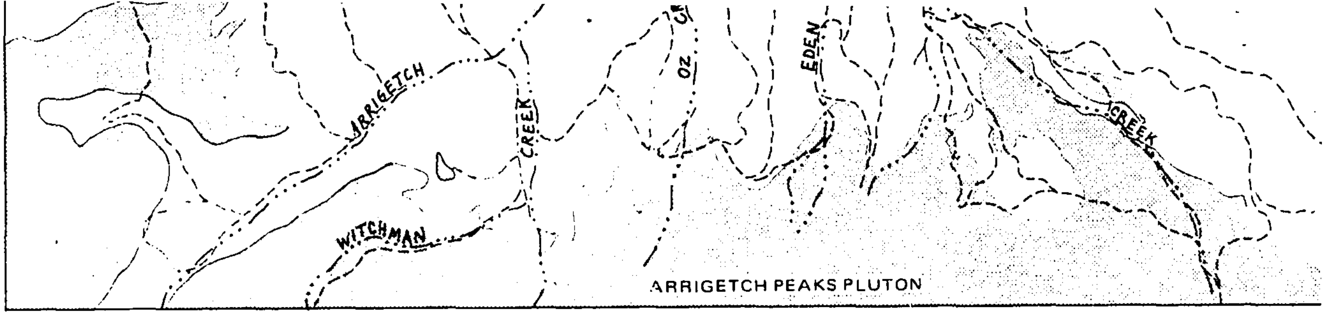

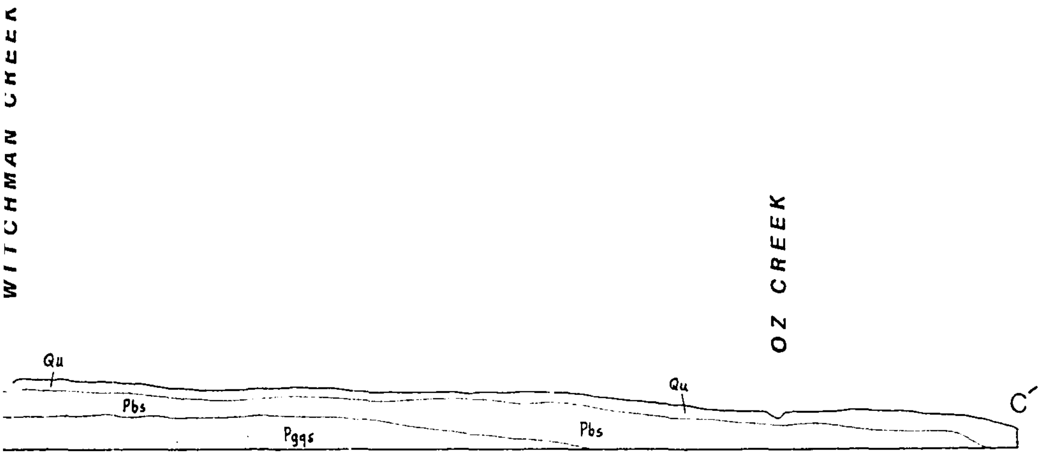

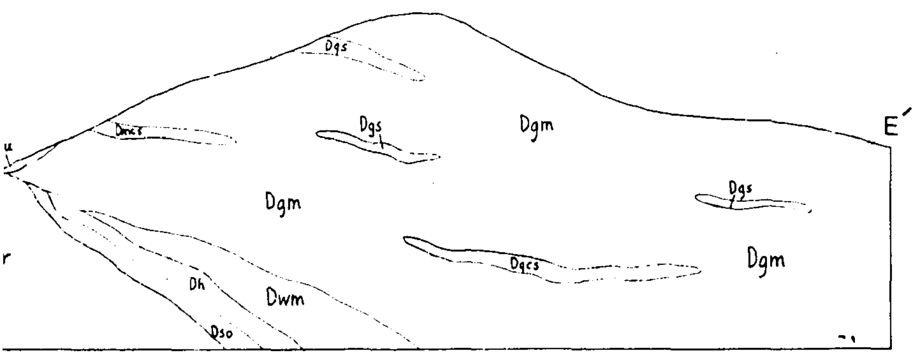

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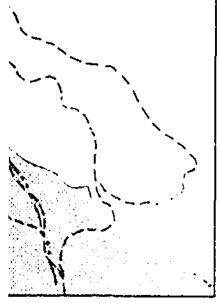

Alkali-feldspar is perthitic; plagioclase ranges from albite to oligoclase in composition. augen. Quartz and feldspar have local granulated textures in thin section. Recrystalli cassiterite and garnet; secondary minerals include biotite, white mica, chlorite, garnet

Dso Brown to gray, fine- to medium-grained, schistose orthogneiss of the Arrigetch Peaks pl Dgr. Contacts with unit unit Dgr are gradational.

Dh Green, fine- to coarse-grained, calc-silicate and calcareous hornfels and lesser calc-silica

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Dqs Green to gray, medium- to coarse-grained, white mica-chlorite-quartz schist.

Dbs Brown to gray, fine- to coarse-grained, chlorite-white mica-biotite quartz schist with ac

Dgqs Green to buff, fine- to coarse-grained, garnet (almandine ?)-biotite-white mica-chlorite

Dgms Green, fine- to coarse-grained, porphyroblastic, garnet (almandine)-biotite-chlorite schi

Dms Gray to green , fine- to coarse-grained, graphitic, quartz-white mica-chlorite schist. Co

Dgm Gray to pinkish, medium- to coarse-grained, impure calcite marble with accessory dol

Unit Dgm and units Dqcs, Dgs and Dwm (below) are correlated with the Skajit Form possible Silurian to Devonian age was found.

Dqcs Gray to buff, medium- to coarse-grained, quartz-chlorite-white mica-phlogopite calc-sc

Dgs Green, fine- to medium-grained, actinolite greenschist with minor sphene and epidote

Dwm White, coarse-grained, impure calcite marble with accessory quartz, phlogopite, white

Pbs Brown to buff, medium- to coarse-grained, chlorite-white mica-biotite-quartz schist , p Contains local carbonate material and includes local hornfels zones.

Unit Pbs and units Pm and Pgqs (below) may correlate with the lower part of the Skaj

Pm Gray to white, medium- to coarse-grained, calcite marble with accessory quartz, white

Pgqs Brown to buff, medium- to coarse-grained, garnet (almandine ?)-chlorite-biotite-white

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ssory dolomite, quartz, white mica, chlorite and amphibole (tremolite-actinolite).

‹ajit Formation because of lithologic similarity and because one specimen of a phaceloid, rugose coral of

ıite calc-schist with accessory tremolite and alkali-feldspar.

d epidote and accessory plagioclase (albite), ilmenite and hematite and trace chlorite and biotite.

ɔite, white mica, chlorite and plagioclase.

z schist, paragneiss and lesser quartzite with accessory epidote, plagioclase, alkali-feldspar, calcite and actinolite

of the Skajit Formation or with sub-Skajit rocks.

artz, white mica, chlorite and amphibole (tremolite-actinolite).

ɔtite-white mica-quartz schist and paragneiss with accessory plagioclase, alkali-feldspar and actinolite.

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